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UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

INSTREAM FLOW DETERMINATION FOR THE HUNTER CREEK DRAINAGE

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JOHN L. BOAZE AND R. SCOTT FIFER

ROCKY MOUNTAIN STATION

OCTOBER 1977

INSTREAM FLOW DETERMINATION

FOR THE HUNTER CREEK DRAINAGE

by

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1977

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Abstract

Instream flow requirements were determined for selected stream-areas below the existing diversion sites on Hunter Creek, Midway Creek, and No Name Creek; located within the White River National Forest, Pitkin County, Colorado.

The study included collection of hydrologic, fisheries, and water quality data, which were used to evaluate fisheries habitat conditions, fisheries populations, and the recreation-aesthetic resource in relation to various stream flow volume and water levels. A series of photographs were taken at each study site to assist in visually displaying the changes in observed flow levels.

Based upon the study data and results, selected evaluation criteria were developed. These criteria included average velocity, average depth, and wetted perimeter of the study cross-sections. The criteria were used to determine which flow levels and volumes would be necessary to sustain the aquatic and recreation-aesthetic resources.

Water quality of the three study drainages was monitored during the study period, and determined to be excellent over the range of observed flows. Water quality was not considered to be a limiting factor in the determination of required instream flows for the Hunter Creek, Midway, and No Name drainages.

Fish population sampling revealed a significant population of both cutthroat and brook trout. Sampling in Hunter Creek indicated a population of 273 cutthroat trout per acre (32.0 lbs./acre) and 519 brook trout per acre (55.2 lbs./acre). Sampling in Midway and No Name Creeks indicated only a brook trout population with 384 fish per acre in Midway (43.2 lbs./acre), and 516 fish per acre in No Name (41.9 lbs./acre). It is felt that these samples indicate very good resident fish populations, particularly when considering the natural low nutritive levels of the water in these three drainages.

As a result of the study data interpretations, it was determined that by-pass stream flows which would provide for an average velocity of 1.4 ft./sec., an average depth of 0.4 ft., and maintenance of 50% wetted perimeter in Hunter Creek and an average velocity of 1.0 ft./sec., average depth of 0.3 ft., and maintenance of 50% wetted perimeter in Midway and No Name Creek would be sufficient to maintain and protect the existing fisheries resource.

These selected habitat criteria would require by-pass streamflows of 12 cfs. below the Hunter Creek diversion, 5 cfs by-pass streamflows below the Midway Creek diversion, and 4 cfs by-pass streamflows below the No Name Creek diversion.

An analysis of the visual impacts of decreasing streamflow levels and volume indicates that the required fisheries streamflows would also be sufficient to maintain and protect the recreation-aesthetic resource.

Acknowledgements

We would like to take this opportunity to thank the personnel from the Bureau of Reclamation, Lower Missouri Region and the Colorado Division of Wildlife for their assistance on this study. A special thanks goes to Burt Schulle, P.O. Abbott and Jim Yahnke of the Bureau of Reclamation, and Jerry Bennett, Randy Cotè and Eddie Kochman of the Colorado Division of Wildlife for their assistance in collecting the data and reviewing the manuscript. Also, thanks to Ron Cody, Bureau helicopter pilot for transporting the team to and from the study area safely each day.

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INTRODUCTION

Purpose of Study

The purpose of this study was to determine required instream flow needs below three fryingpan-Arkansas Project diversion sites located on Hunter, Midway and No Name Creeks, Pitkin County, Colorado (Figures 1 and 2). The flow recommendations are made for the protection of the aquatic resources and to satisfy downstream waters needs of the White River National Forest including recreation, aesthetics, wildlife and riparian ecosystem maintenance. The identified flow needs are submitted to the Bureau of Reclamation for by-pass flow requirements at the diversion sites.

History

Bypass flows for the Hunter, Midway and No Name Creeks diversion sites were first recommended to the Bureau of Reclamation by the Fish and Wildlife Service on February 27, 1967 (Table 1). However, another memorandum was sent to the Bureau on February 28, 1967, recommending different flows for the streams (Table 1). The flow recommendations in the second memorandum have been in use since that time.

On January 18, 1977, the Regional Director, Lower Missouri Region Bureau of Reclamation requested documentation of the present stream flow recommendations for these streams from the Fish and Wildlife Service. The Area Manager, Fish and Wildlife Service, Salt Lake City, Utah responded to this request on February 3, 1977 stating that they were unable to determine from their files the methodology used in arriving at the minimum flow recommendations. However, it was apparent that no stream surveys or analyses were made to ascertain the recommended flows. The Area Manager concurred in the recommendation from the Bureau of Reclamation that a joint study be carried out in coordination with the Colorado Division of Wildlife and the U.S. Forest Service to determine the required stream flows using the latest state-of-the-art methods.

Project Description

The Fryingpan-Arkansas Project is a large scale water diversion development which when complete will divert portions of 14 streams at 17 locations in the upper Fryingpan and Roaring Fork drainages (Figure 1). The water is transported through the Charles H. Boustead Tunnel to the Arkansas River drainage in southeast Colorado. The following project description was taken from the Fryingpan-Arkansas Project Final Environmental Statement, April 1975 and updated as of September 1977;

Table 1. Minimum fishery bypass recommendations (cubic feet per second) for the Hunter Creek Collection System presented in memorandums from the Fish and Wildlife Service to the Bureau of Reclamation, February 27 and 28, 1967

February 27, 1967 Memorandum

Month	Total Release	Hunter Creek	No Name Creek	Midway Creek
May	13.6	8.3	3.0	2.3
June	28.3	18.0	6.3	4.0
July	17.8	11.0	3.8	3.0
August	12.6	8.0	2.6	2.0
September	8.6	5.0	2.0	1.6

Natural flows to be bypassed all other months

February 28, 1967 Memorandum

14	8.5	3.0	2.5

Bypasses as limited by availability

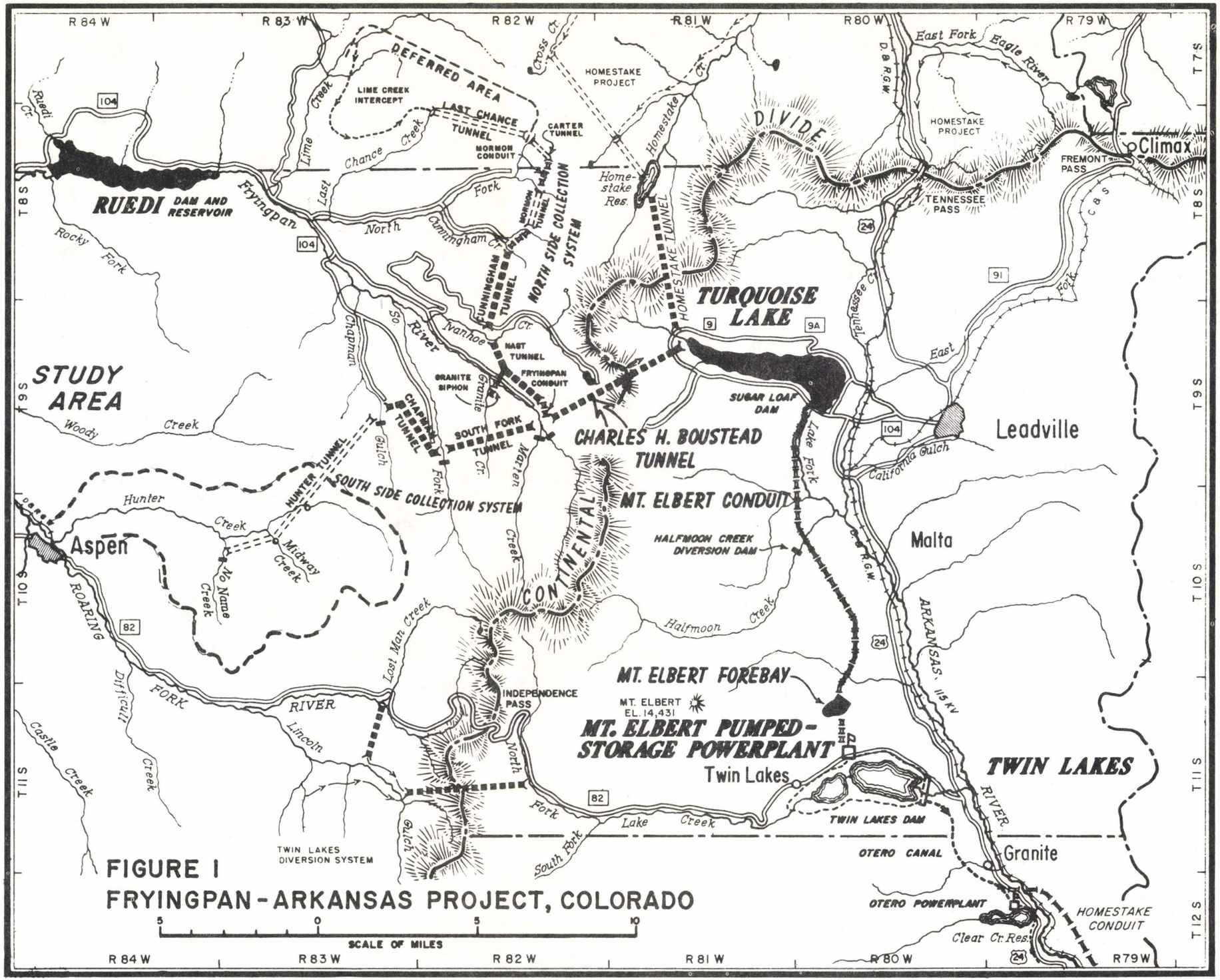


FIGURE 1
FRYINGPAN-ARKANSAS PROJECT, COLORADO

The Fryingpan-Arkansas Project was authorized by P.L. 87-590 in August 1962. Project construction began in 1964 and is scheduled to be completed in 1985. Major Project features include 6 dams and reservoirs with a total storage capacity of 773, 798 acre-feet, 17 diversion structures, 10 tunnels with a total length of 27.2 miles, 1 canal with a length of 5.5 miles, 1 major conduit with a length of 10.5 miles, 2 powerplants with an installed capacity of 211 megawatts, 10.6 miles of transmission line, and 2 municipal and industrial water delivery conduits with a total length of 260 miles (Figure 1). These major features are or will be located in Eagle, Pitkin, Lake, Chaffee, Fremont, Pueblo, El Paso, Otero, Crowley, Bent, Prowers, and Kiowa Counties in Colorado. A total of 30,016 acres of land will be required to accommodate all Project features and to serve related project purposes.

The Hunter Creek collection system (Hunter, Midway and No Name Creeks) is part of the western slope collection system. The Hunter Creek system consists of a 40,000 foot tunnel with three drop inlets. The drop inlets, each with component diversion structure, are located just above the 10,000 foot elevation on No Name, Midway, and Hunter Creeks. No Name diversion, with a drainage area of 6.28 square miles, has a design capacity of 95 ft^3/s. Midway diversion, with a drainage area of 8.39 square miles, has a design capacity of 85 ft^3/s. Hunter Creek, which intercepts 8.53 square miles of drainage, has a capacity of 140 ft^3/s. Hunter Tunnel, with a design capacity of 270 ft^3/s from Hunter Creek to Chapman Gulch, connects with the South Side Collection System.

Study Area

The study area is located within the 42 square mile Hunter Creek Watershed east of Aspen, Colorado (Figure 2). Elevations range from 7,900 feet at the confluence of Hunter Creek with the Roaring Fork River to 13,300 feet in the upper headwaters of the Hunter Creek drainage. The watershed is relatively undistrubed and approximately 80 percent of the study area is being recommended for wilderness study by the Forest Service. The principal vegetative cover includes Engelmann spruce, sub-alpine fir, aspen and a variety of grasses and forbs. Floodplain vegetation is primarily willow, sedges and grasses. The predominant rock type within the sutdy area is granite.

Annual precipitation is high, totaling 30 to 40 inches, most of it is in the form of snow. Snowpacks are deepest during the months of March and April, accumulating from 20 to 70 inches, averaging 1.8 acre feet per acre, or 48,000 acre feet of water annually.

Water originating from the Hunter Creek drainage flows in a westerly direction to the Roaring Fork River, a tributary of the Colorado River. Streamflow distribution is highly dependent on the annual spring runoff when air temperatures are high enough to melt the snowpack. Over 86% of the annual water yield is derived from melting snow during the months of May to August (Figure 3). June is the highest water yield month accounting for 47% of the annual flow. The peak streamflow expected during June for Hunter Creek is approximately 800 cubic feet per second at the Confluence with the Roaring Fork River. The lowest water yield months are December through March when most of the streamflow is derived from ground water sources. The minimum natural stream flow during this period will be about 9 cubic feet per second at the Roaring Fork confluence.

Sampling Stations

Representatives from the Forest Service, Fish and Wildlife Service, Bureau of Reclamation and the Colorado Division of Wildlife selected twelve permanent study sites in the Hunter Creek drainage (Figure 2). The sites were selected for study on the basis of being either 1) "critical riffle areas" required for the maintenance of the fishery or 2) conducive to hydrologic investigations with a stable stream bottom and downstream control. Three of the sites, H-3, H-7 and H-10, were the primary study sites where required instream flow needs were determined just below the diversion structures. The nine remaining stations were monitored to characterize the drainages, in relation to fish populations, flow patterns, and water quality. All stations were studied to ensure that recommended flows below the

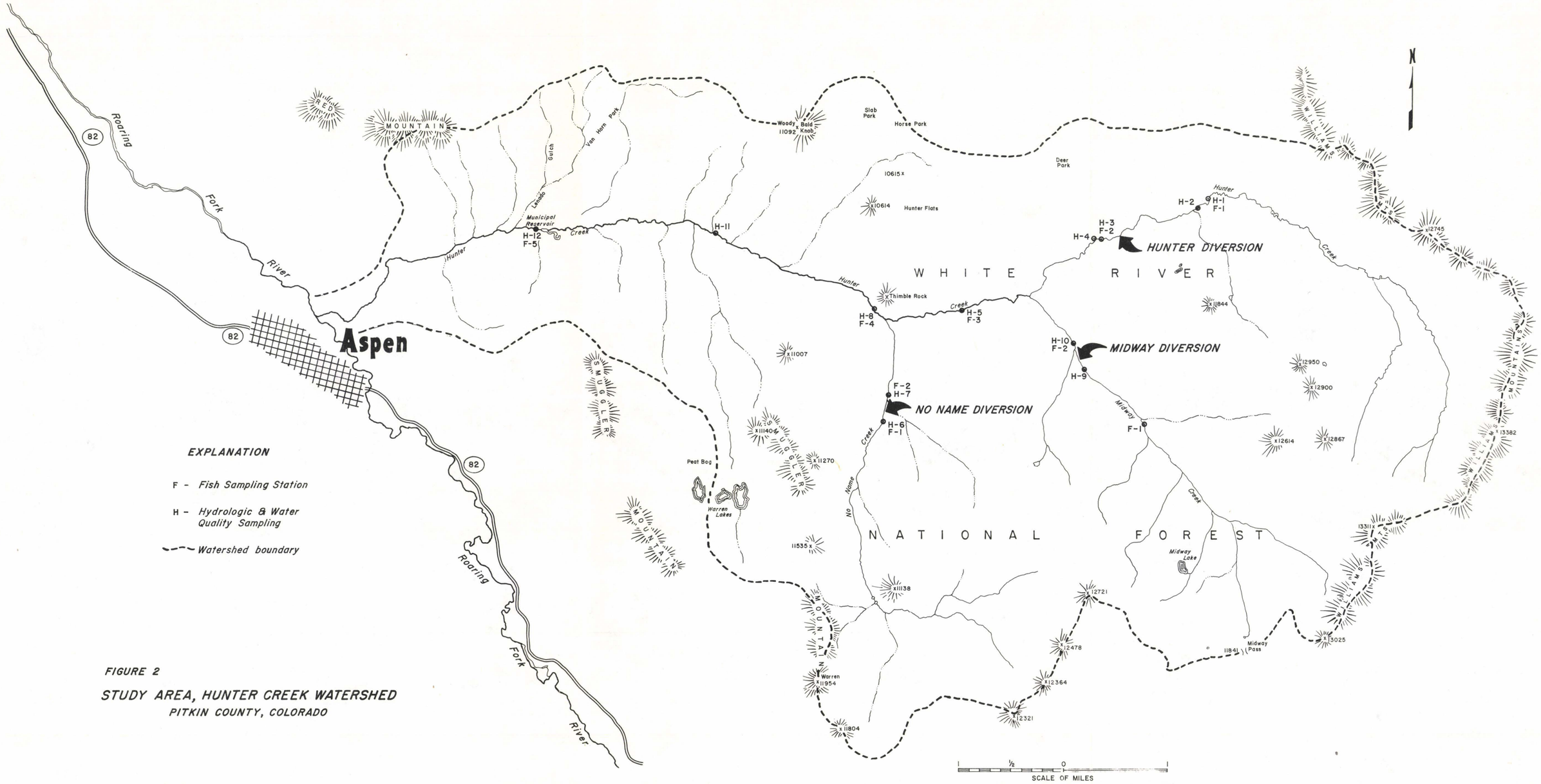
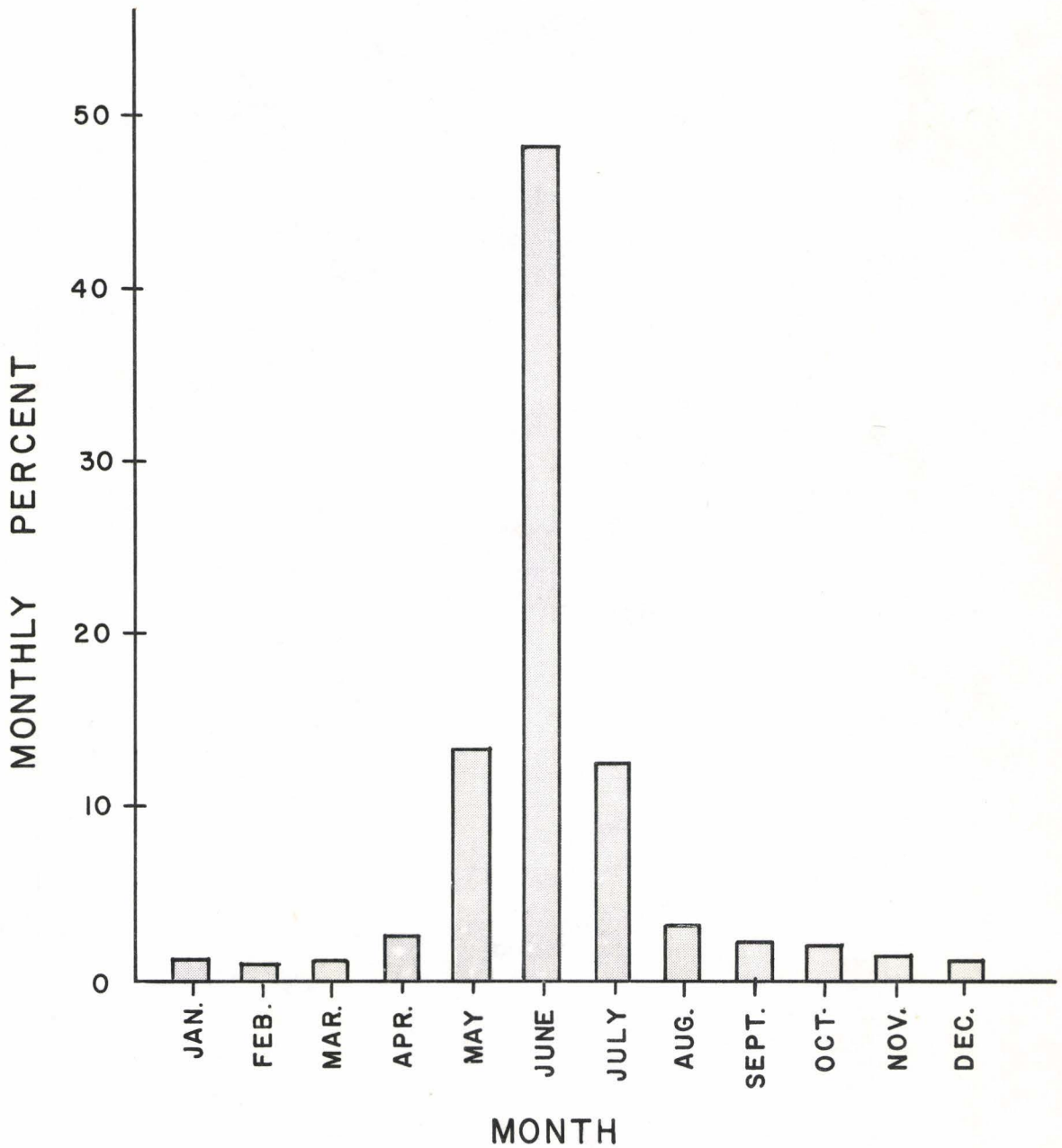


FIGURE 2

STUDY AREA, HUNTER CREEK WATERSHED

PITKIN COUNTY, COLORADO

FIGURE 3 MEAN ANNUAL RUNOFF DISTRIBUTION BY MONTHLY PERCENT, HUNTER CREEK WATERSHED, PITKIN COUNTY, COLORADO U.S.G.S. 1970-74



diversions met downstream flow requirements for fishery and recreation values. A detailed description of each station is as follows:

Station H-1, F-1 - Hunter Creek Above Diversion

This station is located on Hunter Creek 1.2 miles above the Hunter Creek diversion structure (Figure 4). Stream gradient is low, about 0.8 percent. At the stream transect point, the channel width is 13 feet during full stage. At the time of the fish sampling, habitat consisted of deep pools (3-4 feet deep) with undercut banks and long riffle areas, 5-8 inches deep. Pool-riffle ratio for this sample area is approximately 40:60 percent. Substrate was mainly sand and small gravel in the pools and gravel and rocks 1-6 inches in diameter in the riffle areas.

Station H-2 - Hunter Creek Above Diversion

Station H-2 is located on Hunter Creek 1.0 miles above the Hunter Creek diversion structure (Figure 5). Stream gradient is low about 0.3 percent. At the stream transect point the channel width is 16 feet with an average water depth of 1.1 feet during bank full stage. Substrate consisted of gravel and small rocks 1-3 inches in diameter.

Station H-3, F-2 - Hunter Creek Below Diversion

This study site is located on Hunter Creek about 500 feet below the diversion structure (Figure 6). Stream gradient is 1.6 percent. Across the stream transect point, the channel width is 25 feet with an average water depth of 0.6 feet during bank full stage. Fish habitat is typified by riffle areas connecting shallow pools (1-2 feet deep). Pool-riffle ratio is approximately 30:70 percent. Substrate is gravel and small rocks about 1 to 6 inches in diamter. This station is a primary study site where recommendations will be made for required instream flows below the Hunter Creek diversion.

Station H-4 - Hunter Creek Below Diversion

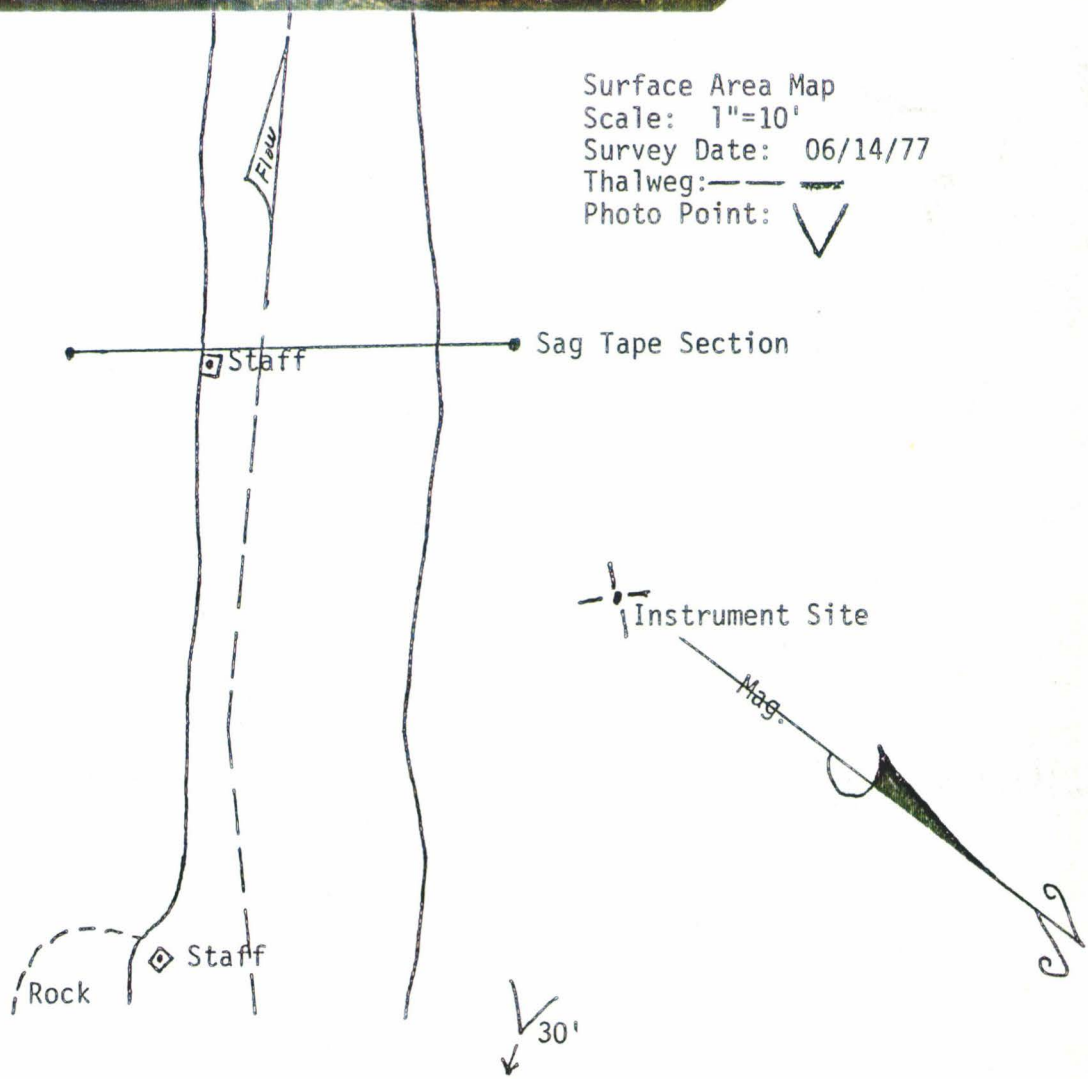
Station H-4 is located on Hunter Creek just below station H-3 (Figure 7). The channel gradient is gentle, about 0.9 percent. During bank full stage the channel width is 16 feet with an average depth of 1.1 feet across the stream transect. Substrate consists of rocks 1 to 6 inches in diameter.

Station H-5, F-3 - Hunter Creek Below Midway Confluence

This station is located on Hunter Creek about 0.75 miles below the Midway Creek confluence (Figure 8). Stream gradient is steep, 4.2 percent. During bank full stage the channel width is 34 feet with

Figure 4. Station H-1, F-1, Hunter Creek, above diversion, Pitkin County, Colorado

Photo: Looking Downstream 07/26/77



Surface Area Map
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Figure 5. Station H-2, Hunter Creek, above diversion, Pitkin County, Colorado

Photo: Looking Upstream 06/14/77

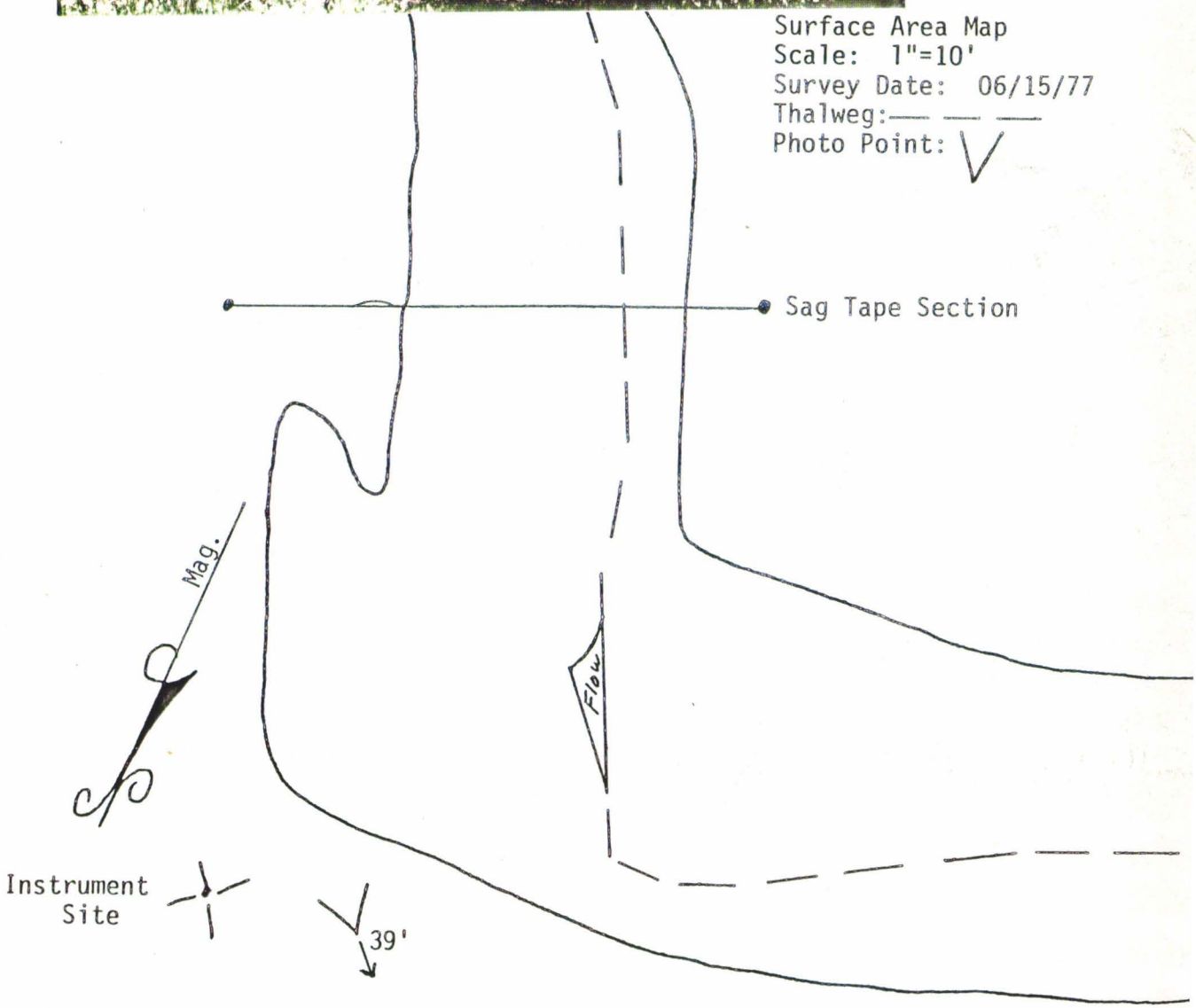


Figure 6. Station H-3, F-2, Hunter Creek, below diversion, Pitkin County, Colorado

Photo: Looking Upstream 06/22/77

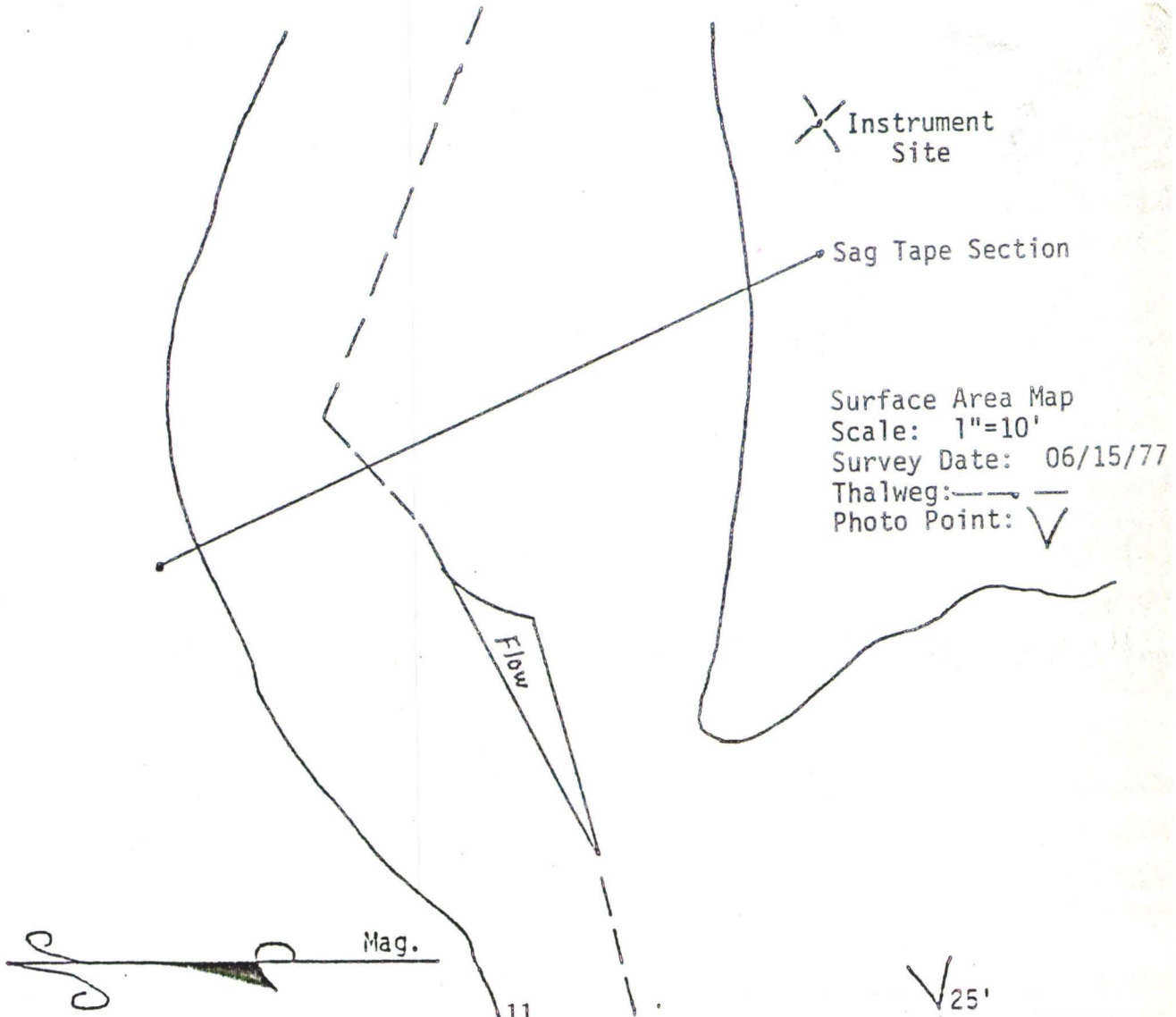


Figure 7. Station H-4, Hunter Creek, below diversion, Pitkin County, Colorado

Photo: Looking
Downstream
07/27/77

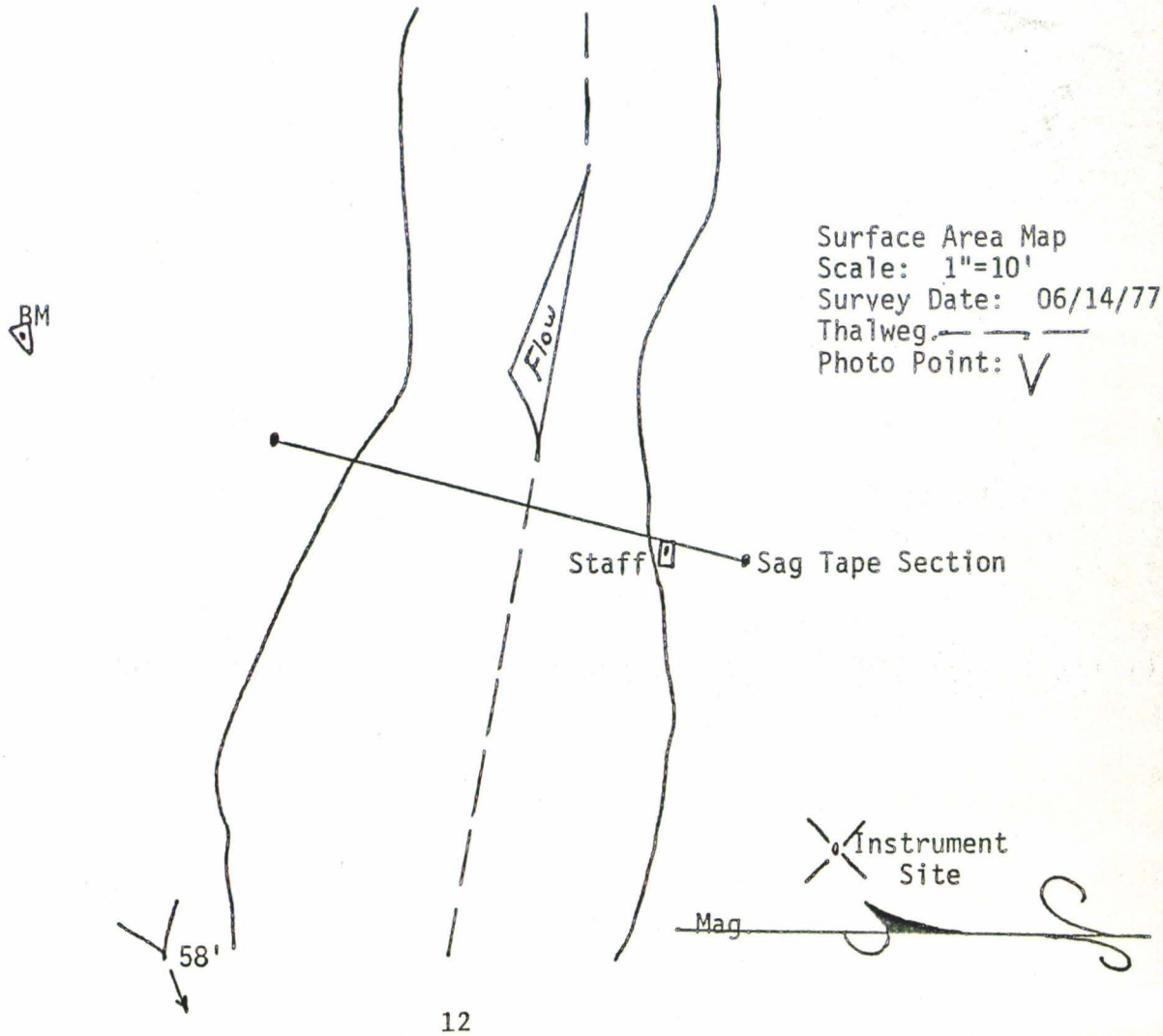
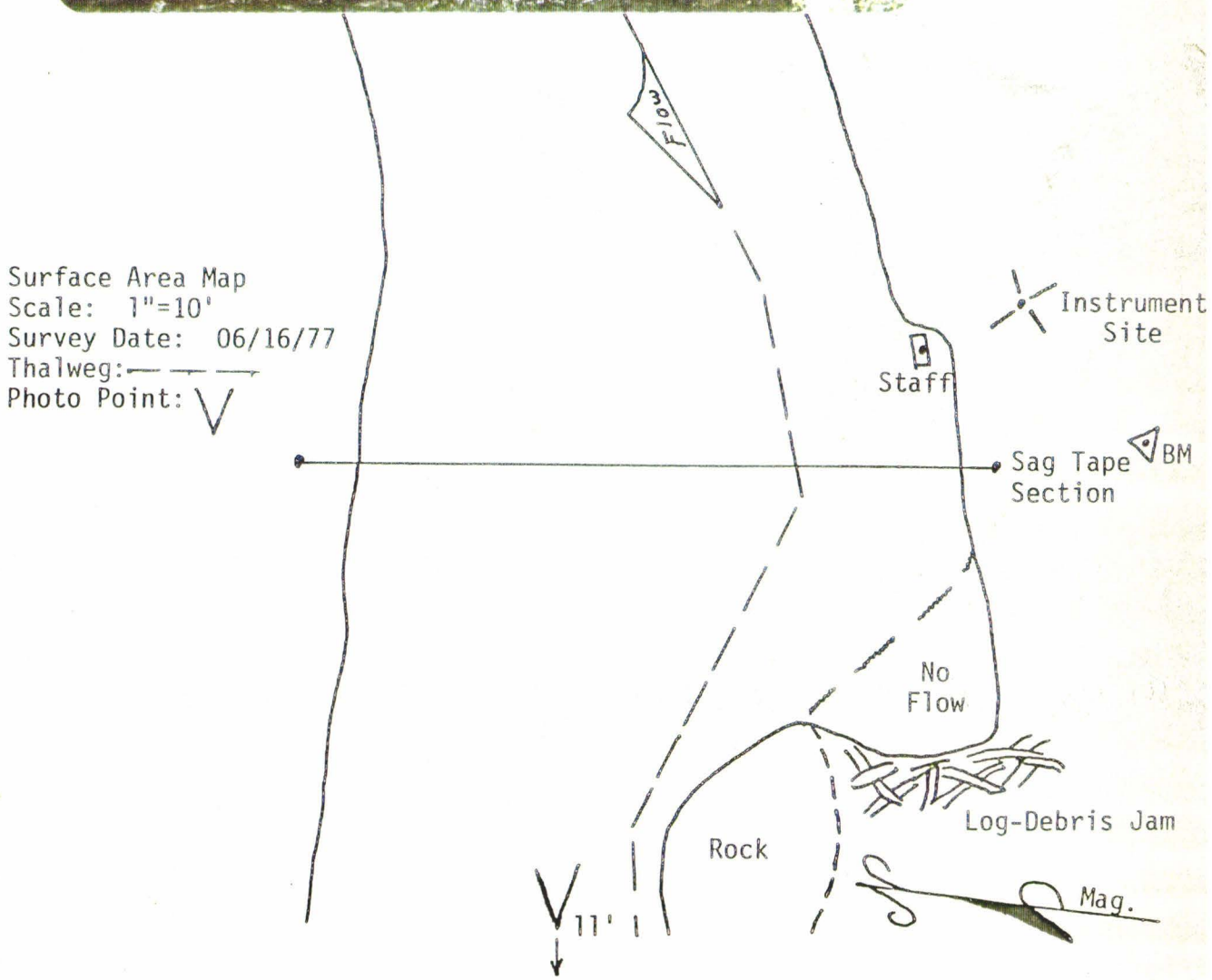


Figure 8. Station H-5, F-3, Hunter Creek, below Midway confluence, Pitkin County, Colorado

Photo: Looking Upstream 06/23/77



an average depth of 1.0 feet across the stream transect. Fish habitat consists of deep pools (1-3 feet deep) connected by steep gradient riffles. Pool-riffle ratio is approximately 60:40 percent. Substrate consists of pebbles and rocks varying in size from 1 inch to 2 feet.

Station H-6, F-1 - No Name Creek Above Diversion

This station is located on No Name Creek about 500 feet above the No Name diversion structure (Figure 9). Stream gradient is 3.5 percent. During bank full stage the channel width is 24 feet with an average water depth of 0.5 feet across the stream transect. Fish habitat is typified by shallow pools (6 inches - 1 foot deep) and undercut banks. Pool-riffle ratio is approximately 40:60 percent. Substrate is mainly small rocks, 1 to 6 inches in diameter.

Station H-7, F-2 - No Name Creek Below Diversion

This station is located on No Name Creek about 0.2 miles below the No Name diversion structure (Figure 10). This is a primary study site, recommendations will be made for required instream flow below the No Name diversion. Pools and short steep gradient riffles typified the fish habitat. Pool-riffle ratio is approximately 70:30 percent. Substrate ranged from gravel to 6 inch rocks. The stream gradient is steep, 5.7 percent. During bank full stage the channel width is 16 feet with an average depth of 0.6 feet across the stream transect.

Station H-8, F-4 - Hunter Creek Below No Name Confluence

This station is located on Hunter Creek about 0.2 miles below the confluence of No Name Creek (Figure 11). Stream gradient is steep, 5 percent. During bank full stage the channel width is 28 feet with an average depth of 1.2 feet across the stream transect. Fish habitat consists of deep pools (1-4 feet deep) connected by steep gradient riffles. Pool-riffle ratio is approximately 60:40 percent. Substrate is mainly rocks 1 to 6 inches in diameter, with a predominance of 3 inch diameter rocks.

Station H-9 - Midway Creek Above Diversion

Station H-9 is located on Midway Creek about 400 feet above the diversion structure (Figure 12). Stream gradient is 3 percent through the study area. During bank full stage the channel width is 24 feet with an average depth of o.6 feet across the stream transect.

Station F-1 - Midway Creek Above Diversion

This station is located approximately one mile above the diversion site. Fish habitat consists of shallow pools, 6 to 12 inches deep, connected by short riffles. Substrate is mainly small rocks (1-6 inches in diameter) with small amounts of silt and sand. Pool-riffle ratio is approximately 70:30 percent.

Figure 9. Station H-6, F-1, No Name Creek above diversion, Pitkin County, Colorado

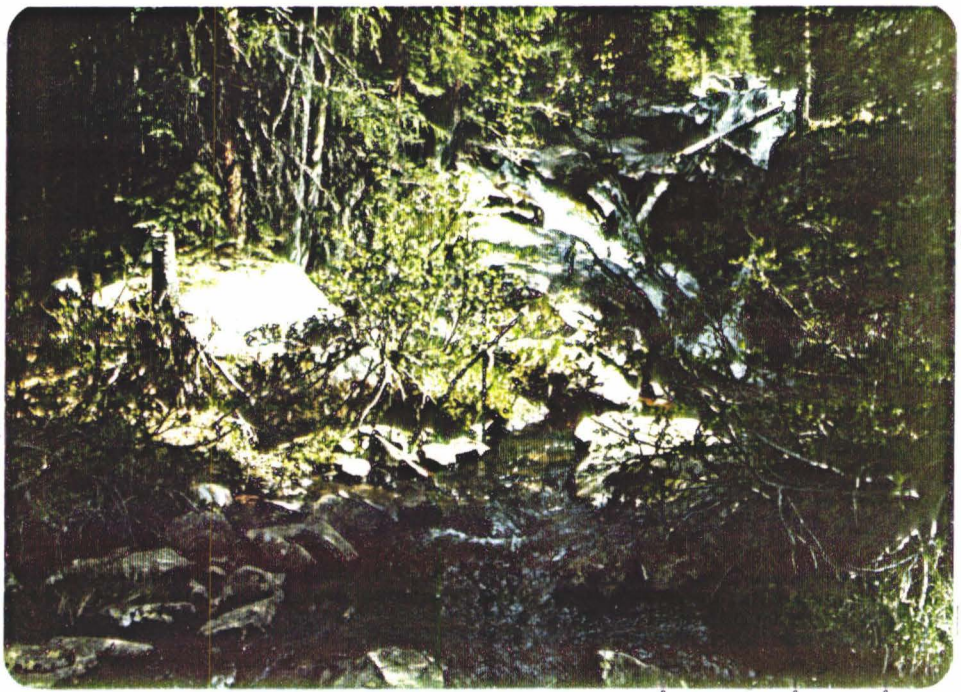


Photo: Looking Upstream 06/22/77

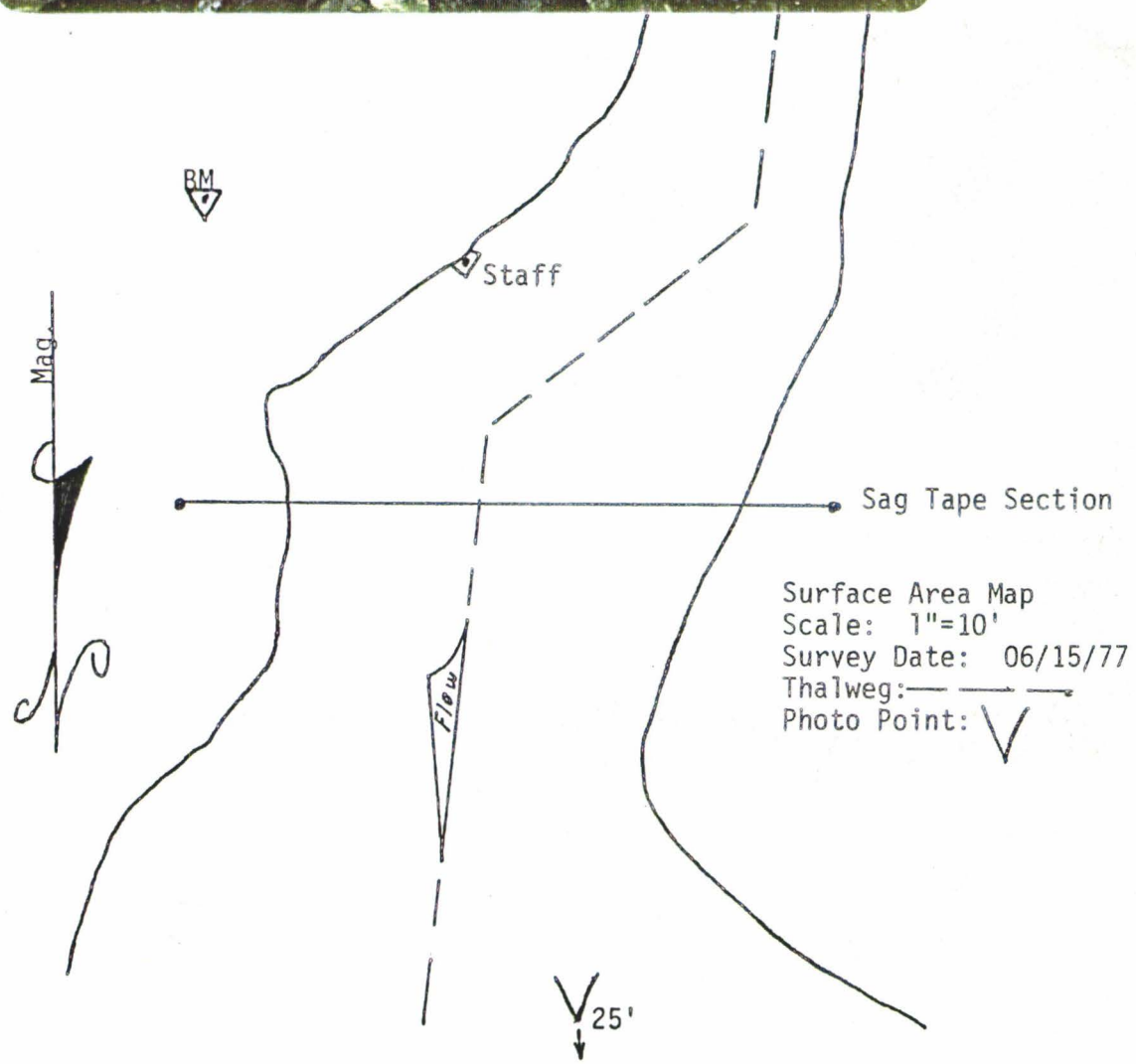


Figure 10. Station H-7, F-2, No Name Creek, below diversion, Pitkin County, Colorado

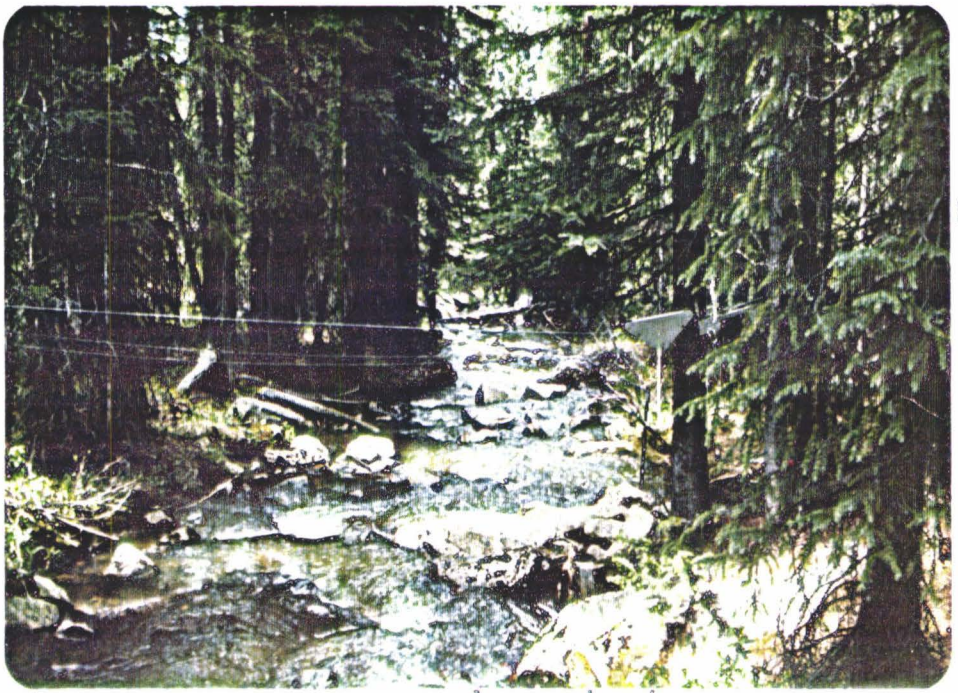
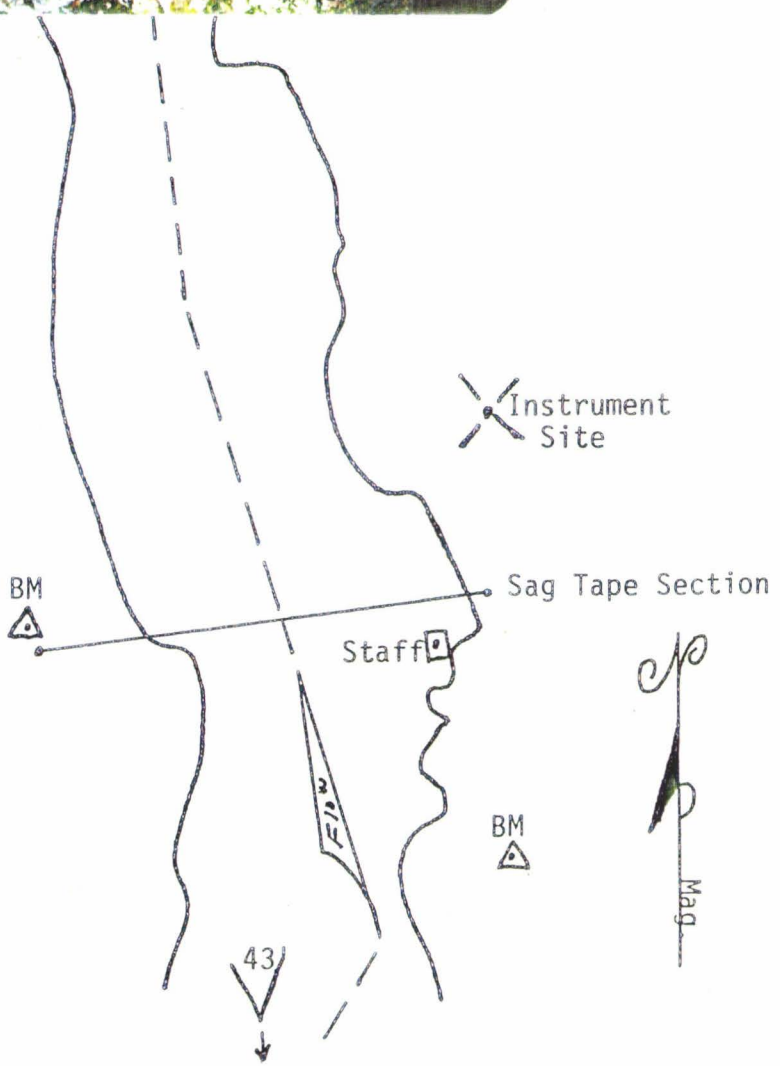


Photo: Looking Downstream 06/22/77



Surface Area Map
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Figure 11. Station H-8, F-4, Hunter Creek, below No Name confluence, Pitkin County, Colorado

Photo: Looking Downstream 06/23/77

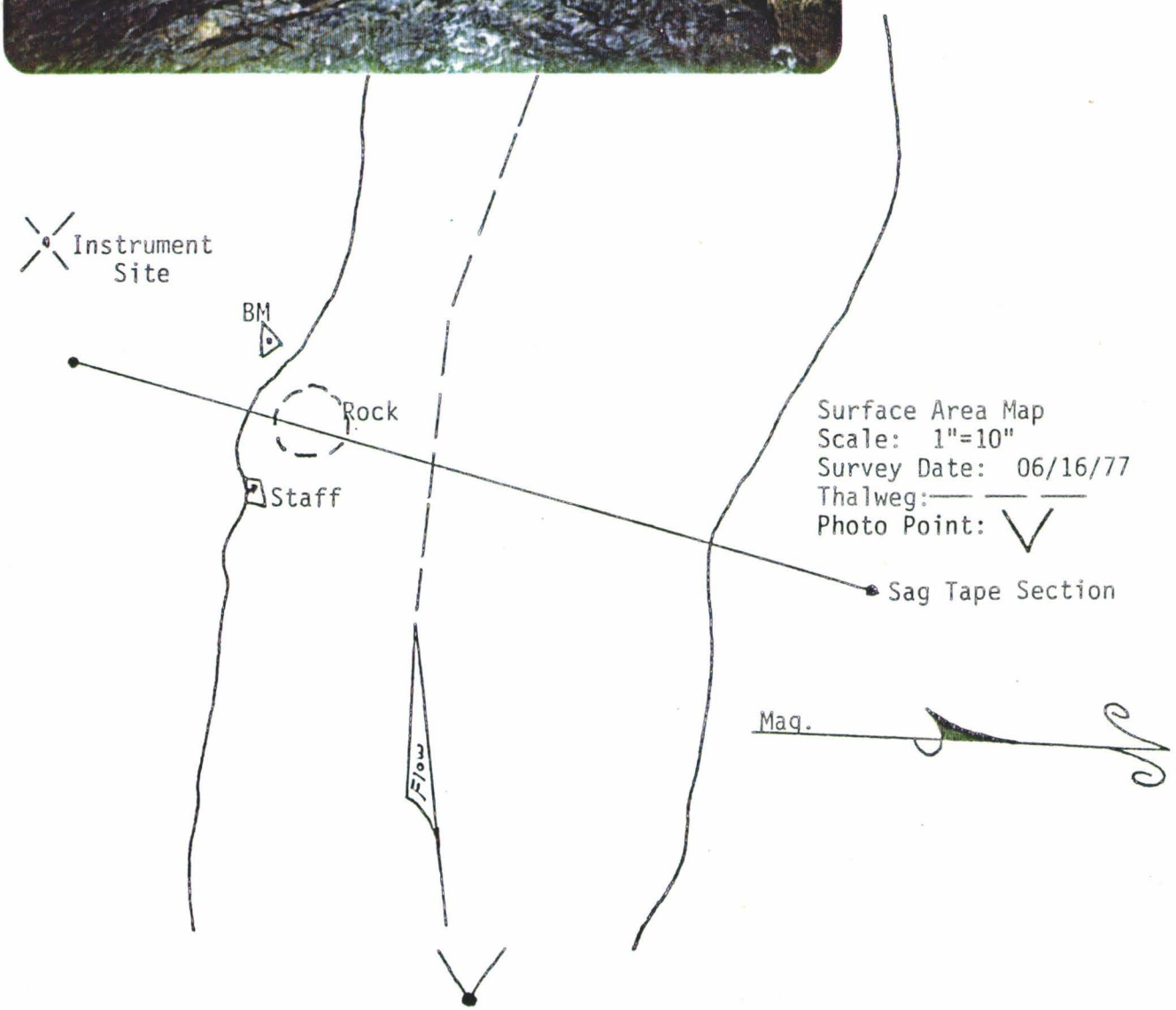
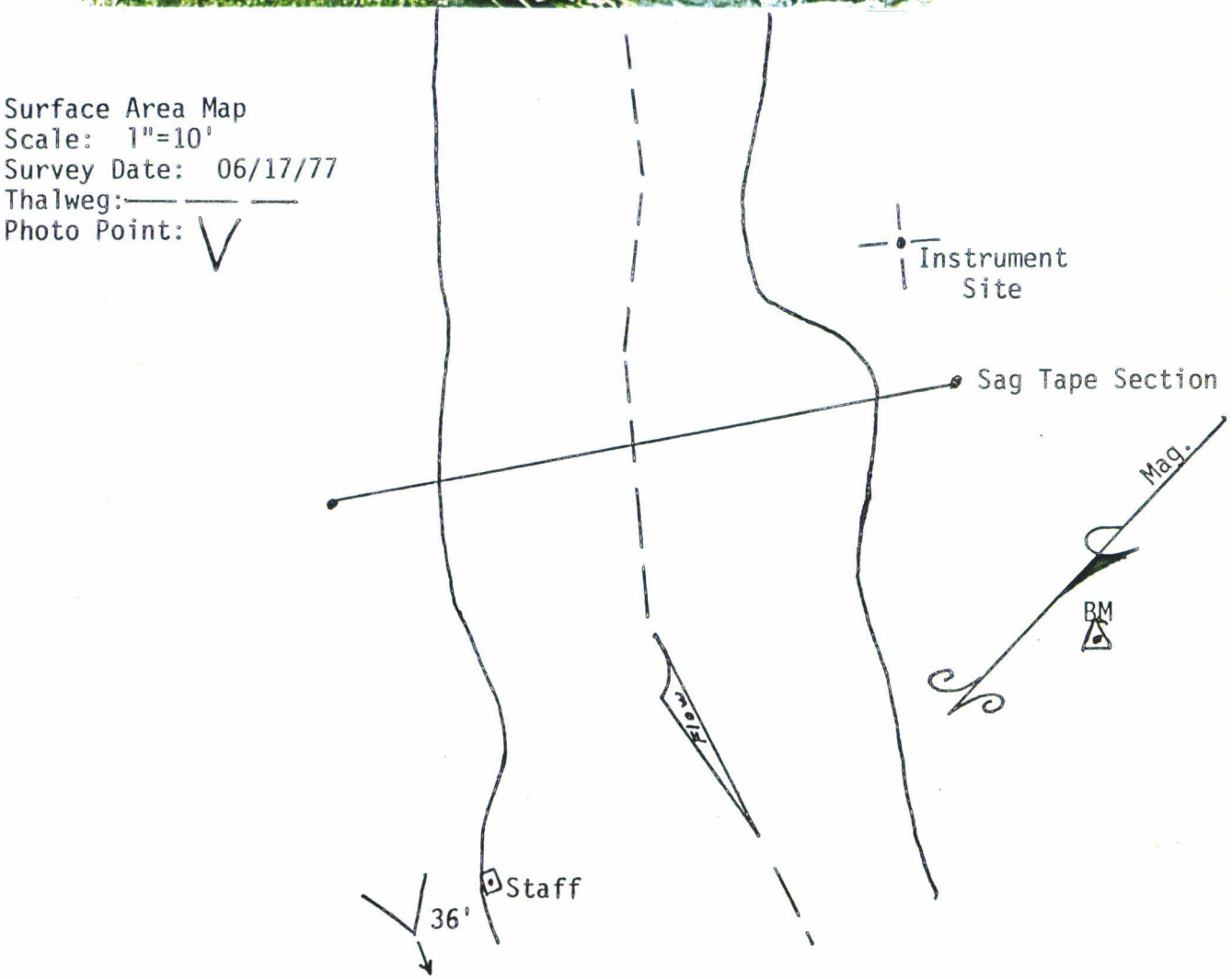


Figure 12. Station H-9, Midway Creek, above diversion, Pitkin County, Colorado

Photo: Looking Upstream 06/23/77



Station H-10, F-2 - Midway Creek Below Diversion

This station is located on Midway Creek about 0.25 miles below the diversion structure (Figure 13). This station is a primary study site. Recommendations for required instream flows below the Midway Diversion will be made from the data collected at this site. The stream gradient is steep, 4.3 percent. During bank full stage the channel width is 25 feet with an average depth of 0.8 feet across the stream transect. Substrate is mainly gravel and rocks, 4 inches and above in diameter. Fish habitat is mainly pools which are 1-2 feet deep. Pool-riffle ratio is approximately 80:20 percent.

Station H-11 - Hunter Creek Above Dam

Station H-11 is located on the lower Hunter Creek about 1.4 miles above the breached municipal reservoir (Figure 14). Stream gradient is gentle, 1.3 percent. During bank full stages the channel width is 41 feet with an average depth of 0.8 feet across the stream transect.

Station H-12, F-5 - Hunter Creek Below Dam

This station is located on lower Hunter Creek about 150 feet below the breached municipal reservoir (Figure 15). Stream gradient is gentle 1.3 percent. During bank full stage the channel width is 39 feet with an average depth of 0.8 feet across the stream transect. Fish habitat is typified by deep riffles (6 inches to 1 1/2 foot deep) and small pools. Pool-riffle ratio is approximately 30:70 percent.

Figure 13. Station H-10, F-2, Midway Creek, below diversion, Pitkin County, Colorado

Photo: Looking Downstream 06/23/77

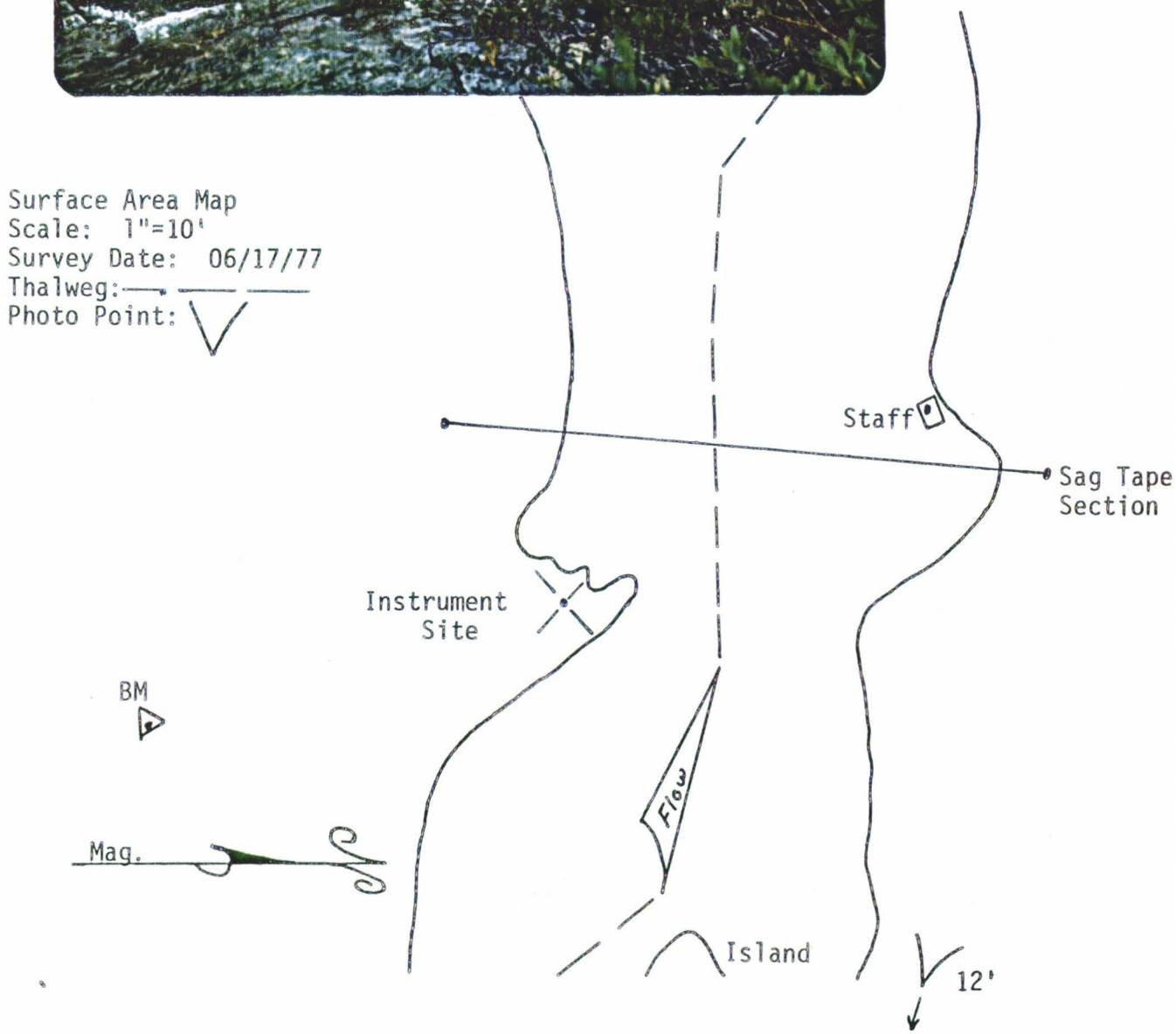


Figure 14. Station H-11, Hunter Creek, above dam, Pitkin County, Colorado

Photo: Looking Upstream 06/21/77

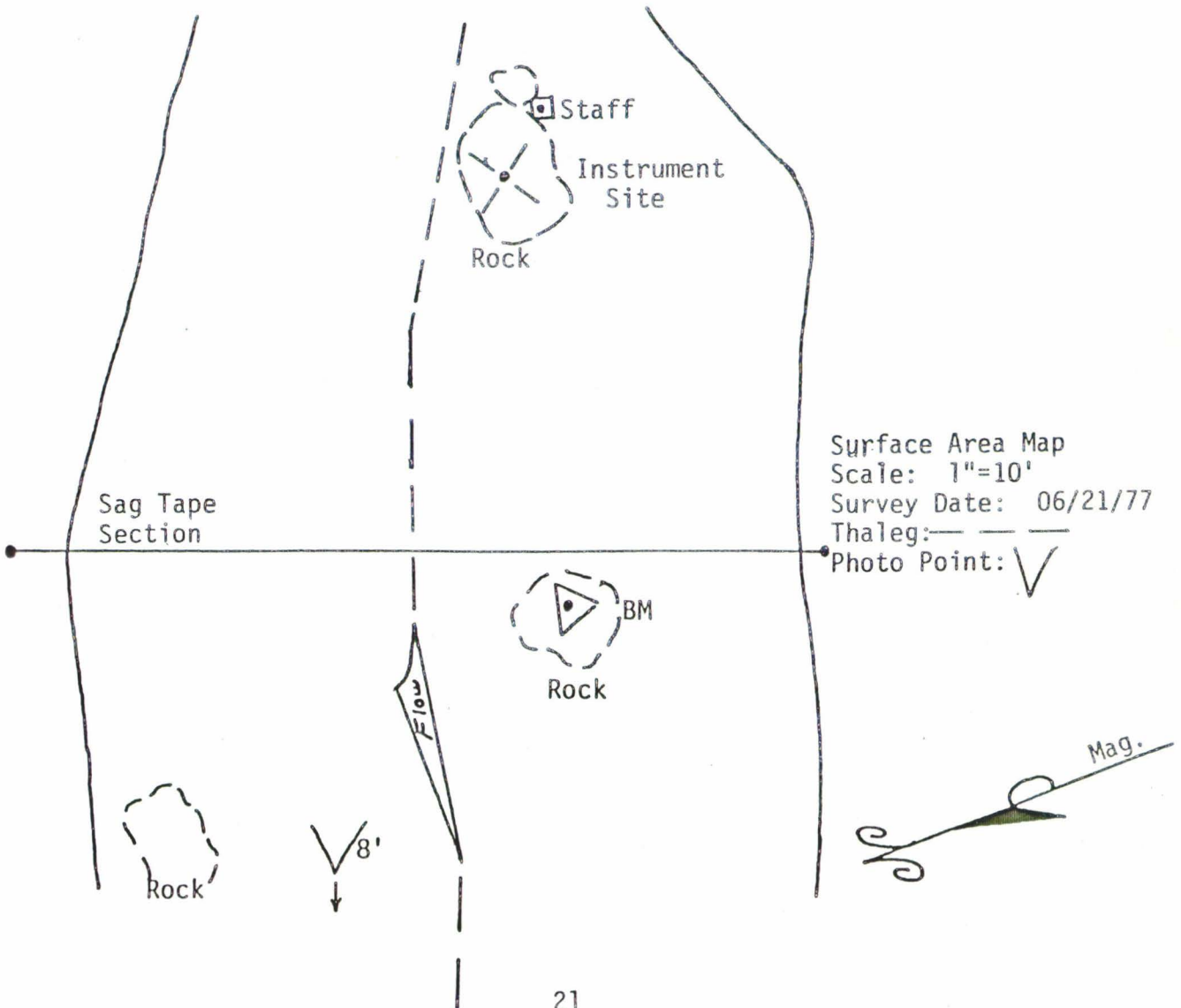
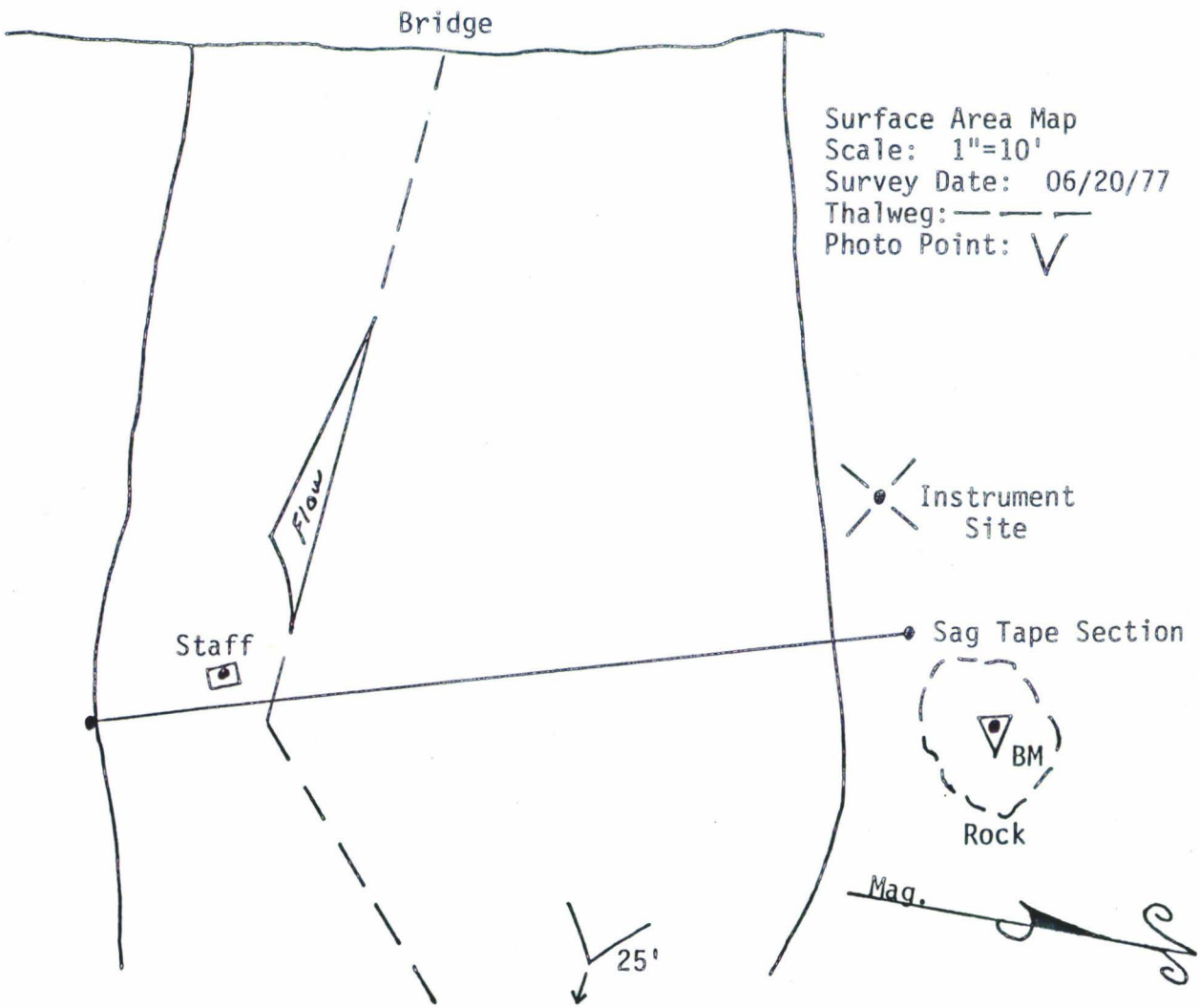


Figure 15. Station H-12, F-5, Hunter Creek, below dam, Pitkin County, Colorado

Photo: Looking Downstream 06/29/77



Methods

The methodology for determining instream flow requirements was a combination of the latest procedures developed by the U.S. Forest Service Region 2, the U.S. Fish and Wildlife Service, and the Colorado Division of Wildlife. The study used a "modified" version of the Critical Area (R-2) Method (Silvey, Kochman, 1976) which utilizes an interdisciplinary field team to determine flow needs for fisheries and aesthetics.

During the study, stream flow measurements were taken seven times between June 14, 1977 and August 11, 1977, to observe the variations in stream discharge, velocity, depth and water quality during high and low flow periods. Stream cross section profiles were plotted at each site to monitor the changes in cross sectional area, wetted perimeter depth and width. In addition, fish populations were sampled during the week of July 27th to determine species present and size classes. Photographs were also taken on each visit to visually display the changing flow levels. Based upon this information, streamflow requirements were determined by selecting a discharge with sufficient depth, width and velocity to sustain the existing fishery and aesthetic resources in the Hunter Creek drainage.

Hydrologic Sampling

Trout production depends on having sufficient stream flow to provide for food, shelter, reproduction, high water quality and fish passage. These requirements are related to certain hydraulic conditions, such as water depth, velocity and wetted perimeter. To monitor these changing conditions during different flow levels, stream transects were established across each study site.

Each site was surveyed with a transit and rod to accurately map the study area and locate the stream transect. Stream cross-section profiles were developed at the sites using the R-2 Cross Computer Program, a sag-tape method of measuring channel cross sections (Silvey, 1976). A tape was szretched between two level stakes located on opposite streambanks perpendicular to the stream flow. The stakes were half inch steel "re-bar" anchored in the ground. Depth measurements were taken from the tape to the channel bottom at one foot intervals along the cross section. The computer program corrected for depth errors due to tape sag and produced a plotted profile of the stream cross-section.

Stream discharge and stage measurements taken during the field study were drawn directly on the plotted profile. The computer program then calculated the wetted permimeter, hydraulic radius, cross sectional area and maximum water depth for each of the measured water levels. The R-2 Cross Program also synthesizes stream discharge and velocity at selected water levels based on Manning's streamflow formula. However, during this study the actual stream discharge and velocity measurements were taken at different flow levels, eliminating the need for computations, based on Manning's formula. The R-2 Cross Program provided information limited to the hyraulic geometry of the stream channel.

Stream discharge measurements were made with a Pygmy current meter. The standard method for determining stream discharge, as outlined in "Streamflow Measurement" (Shields, (unknown)), was used during the study. Staff gages were installed at each site to record changing flow levels and determine stage-discharge relationships.

Fish Population Sampling

Nine sampling stations were selected for the three streams to represent the habitat types present (Figure 2). Five stations were selected on Hunter Creek while two stations each were established on Midway and No Name Creeks. Each station was 528 feet (0.1 mile) long. Table 2 presents the average widths, flows and acreage for each station.

Fish were collected by sodium cyanide from July 27-30, 1977. The use of this chemical over electrofishing was necessitated because of the very low conductivity of the water which was 35 micromhos/centimeter at the lowermost stations and less at the upstream szations. A biologist from the Colorado Division of Wildlife applied the chemical at the rate of 3 ounces per cubic foot of water flowing at the time.

Block nets were placed at the lower end of each sample station to prevent the fish from moving out of the sample area. Fish react to this chemical by showing the characteristic "cyanide syndrome" (surfacing, circling and drifting), therefore a block net was not needed at the upper end of the sample area. Fish were collected by dip net and placed in buckets containing fresh water. They revived in one-two minutes, and it appeared that mortality from the chemical was near zero.

Collection of all fish in an area was not 100 percent as had been expected. At the time treatment began, various sizes of marked

Table 2. Average width, flow and area at the time of sampling for each station on Hunter, Midway and No Name Creeks, Pitkin County, Colorado, July 27-30, 1977

Station	Average Width (ft.)	Flow (cfs)	Area (Acres)
	Hunter Creek		
H-1, F-1	18.4	14.7	0.22
H-3, F-2	18.1	14.2	0.22
H-5, F-3,	28.0	23.4	0.34
H-8, F-4	25.6	20.4	0.32
H-12, F-5	34.3	28.7	0.42
	Midway Creek		
F-1	17.8	9.7	0.22
H-10, F-2	18.8	9.4	0.23
	No Name Creek		
H-6, F-1	15.4	3.4	0.19
H-7, F-2	14.6	5.5	0.18

cfs - cubic feet per second

fish were released into five of the nine sample areas. Recovery varied from 40 to 80 percent. It appeared that the smaller fish (<6 inches) were avoiding capture by escaping under the rocks. Therefore, fish population estimates in this report are considered minimal.

Following collection, all fish were measured to the nearest 0.1 inch (total length), weighed to the nearest 0.01 pounds and released back to the stream. The condition factor (C) for fish 6 inches or greater, total length, was determined using the following formula:

$$C(TL) = \frac{W\ 10^5}{L^3}$$

where

C	is the condition factor.
TL	is the total length.
W	is the weight in hundredths of pounds.
L	is the length in inches and tenths.
10^5	is a coefficient used to bring the value of C(TL) near unity.

Water Quality Sampling

The recommended required flow must be of sufficient quality to remain favorable to fish and aquatic life. Because reduced streamflows may adversely affect the streams water quality, certain parameters were monitored throughout the summer to determine the variation in water quality at different flow stages. The parameters that were evaluated were selected because they can be compared to established water quality standards necessary for fish and aquatic organism survival. The parameters monitored include: temperature, specific conductivity, d ssolved oxygen, alkalinity, pH and suspended solids.

Water temperatures were measured using a standard dry bulb thermometer and recorded in degrees Celsius. Specific conductivity was measured with a Beckman Conductivity Meter and recorded in micromhos/centimeter. Dissolved oxygen, alkalinity and pH were analyzed with a Hach Water Chemistry Kit. Suspended solids were measured by Grand Junction Laboratories from depth integrated water samples collected at the study sites and reported in milligrams per liter.

Recreation and Aesthetics

The recreational-aesthetic instream flow analysis examined the visual impact of the decreasing stream flows on the landscape. The study analyzed the changes a reduced streamflow would have on the natural flow season, streambed configuration and composition, stream gradient,

riparian vegetation, special stream features and the general landscape character (Mittman, 1976).

Upstream and downstream photo points of each study area were established and photographs taken at each visit to visually display the different flow levels encountered. These photographs, together with field observations, were the basis for evaluating the visual impact of different stream flows to the landscape's character.

RESULTS

Hydrologic Sampling

The stream data collected at Stations (H-3, F-2), (H-10, F-2), and (H-7, F-2) are summarized in figures 16-18. These figures also display the stream profiles at the various water levels observed during the study.

The streamflow patterns are characteristic of high elevation mountain streams in Colorado. Stream discharge decreased throughout the study period as flows became less dependent on the melting snowpack. The higher streamflows observed on July 27th and 28th resulted from summer showers preceeding the measurements.

The relationships between stream discharge and the other measured hydraulic parameters were dependent upon the stream channel geometry (figures 16-18). Generally, as discharge decreased the other parameters also decreased. However, in some instances, as the stream discharge decreased, average depth and velocity increased slightly due to changing channel geometry. For example, if a lowering water level eliminates a shallow area and concentrates the flow toward the deeper stream center, the average depth value across the section will increase. The result is a lower stream discharge with an increased average depth. A similar relationship could exist between discharge and average velocity.

Fish Population Sampling

Table 3 presents the results of fish sampling for the Hunter Creek drainage. The upper portion of Hunter Creek is apparently supporting only cutthroat trout. However, it does not appear to be a pure strain of cutthroat trout based on the variation in the spotting pattern of the fish (Figures 19-20). At some point in time other cutthroat and possible rainbow trout were introduced, resulting in hybridization.

The reason for the presence of only cutthroat trout in the upper section of Hunter Creek while nearly a pure population of brook trout exists in the lower reaches cannot be explained (Table 3). No physical barrier could be located that would serve to separate the two species.

Midway and No Name Creeks are supporting only Brook trout. These streams may have been barren or the brook trout may have replaced the indigenous cutthroat trout.

Figure 16. Physical parameters and stream profile of station H-3, F-2, Hunter Creek below diversion, Pitkin County, Colorado.

Date	Discharge (cubic ft./sec.)	Stage (ft.)	Average Velocity (ft./sec.)	Average Depth (ft.)	Wetted Perimeter (%)	Hydraulic Radius (ft.)	C.S. Area (ft^2)	Max. Depth (ft.)
06/15/77	31.53		1.80	.60	71	.587	17.51	1.0
06/22/77	15.30	No Staff	1.77	.37	51	.408	8.62	.7
06/30/77	12.37		1.48	.39	50	.402	8.33	.7
07/06/77	9.43		1.39	.33	43	.374	6.75	.6
07/14/77	6.30		1.28	.31	37	.315	4.89	.5
08/10/77	4.40		.87	.31	38	.319	5.08	.5

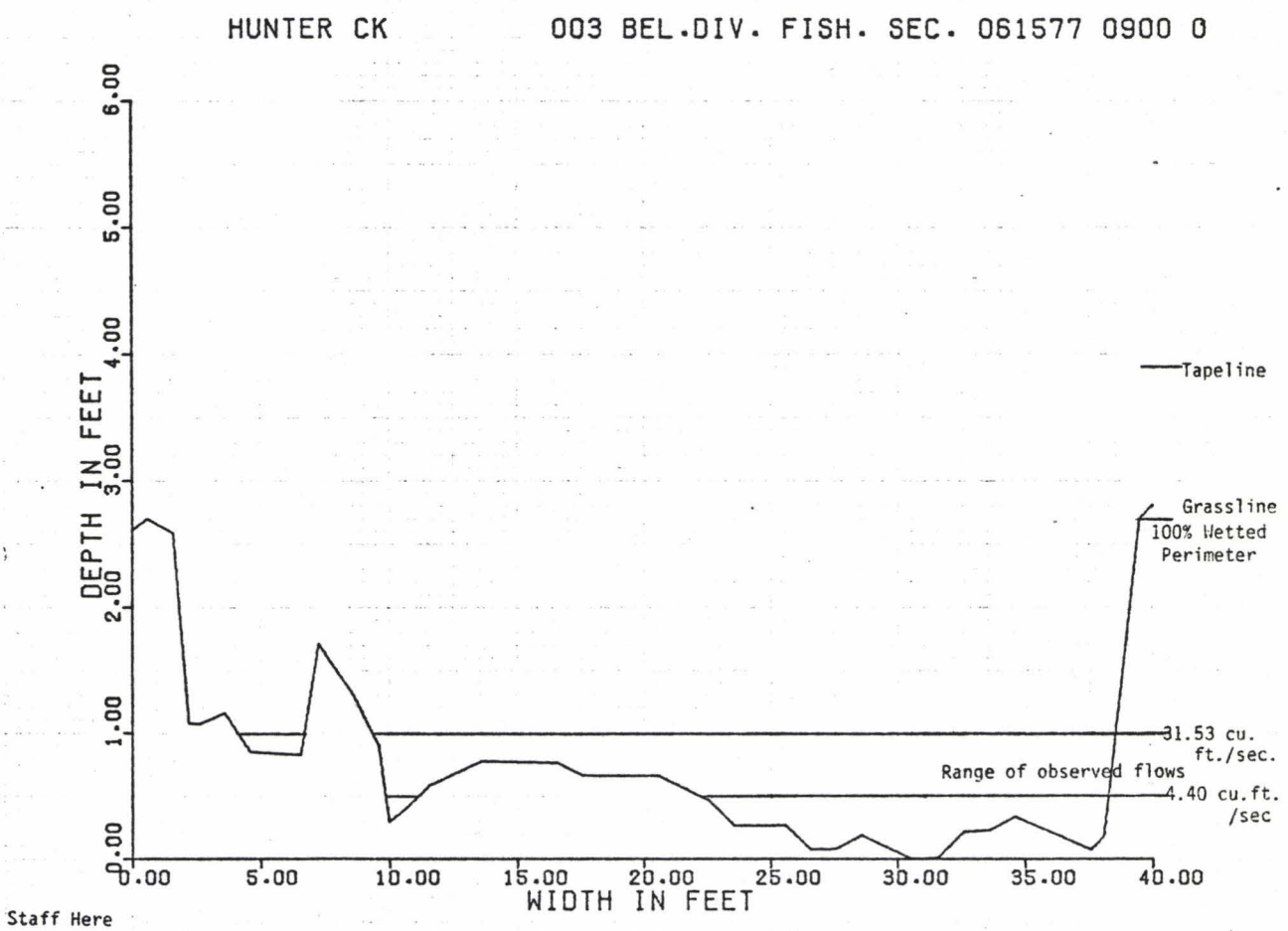


Figure 17. Physical parameters and stream profile of station H-10, F-2, Midway Creek below diversion, Pitkin County, Colorado.

Date	Discharge (cubic ft./sec.)	Stage (ft.)	Average Velocity (ft./sec.)	Average Depth (ft.)	Wetted Perimeter (ft)	Hydraulic Radius (ft.)	C.S. Area (ft^2)	Max. Depth (ft.)
06/17/77	30.55	1.3	1.54	.77	82	.769	19.76	1.5
06/23/77	12.60	.9	1.23	.44	74	.438	10.20	1.1
07/01/77	8.23	.8	1.02	.38	67	.382	8.05	1.0
07/07/77	7.61	.7	1.23	.36	55	.359	6.18	.9
07/15/77	4.39	.6	.96	.30	48	.300	4.53	.8
07/28/77	9.42	.9	.92	.44	74	.438	10.20	1.1
08/11/77	3.33	.6	.73	.30	48	.300	4.53	.8

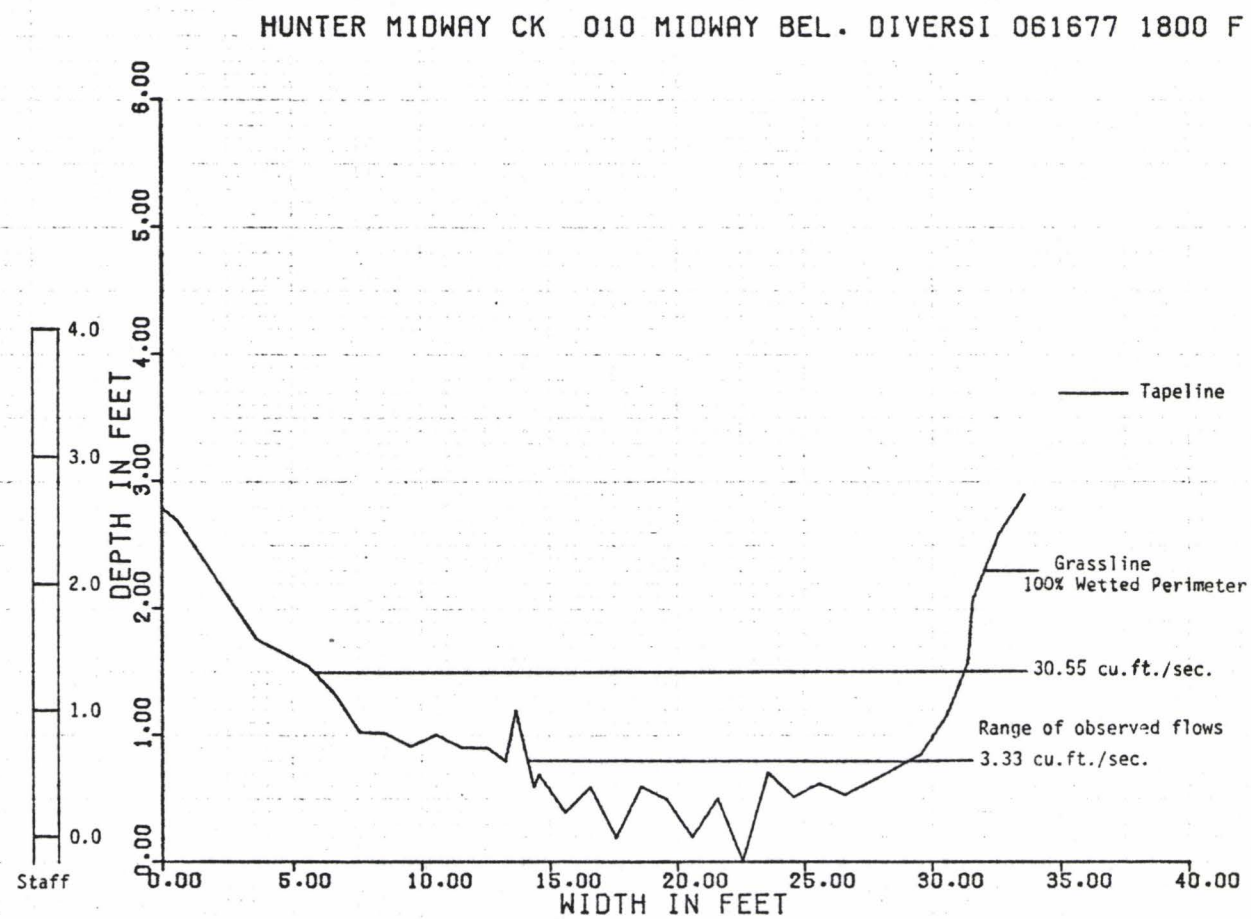


Figure 18 . Physical parameters and stream profile of station H-7, F-2, No Name Creek below diversion, Pitkin County, Colorado.

Date	Discharge (cubic ft./sec.)	Stage (ft.)	Average Velocity (ft./sec.)	Average Depth (ft.)	Wetted Perimeter (%)	Hydraulic Radius (ft.)	C.S. Area (ft^2)	Max. Depth (ft.)
06/15/77	14.34	4.2	1.48	.59	86	.486	9.68	1.4
06/22/77	6.03	4.5	1.14	.33	74	.307	5.26	1.1
06/30/77	5.53	4.6	1.33	.27	71	.255	4.15	1.0
07/06/77	8.65	4.5	1.64	.33	74	.307	5.26	1.1
07/14/77	3.50	4.7	1.11	.20	68	.200	3.14	.9
07/29/77	5.54	4.5	1.05	.33	74	.307	5.26	1.1
08/10/77	3.01	4.7	.95	.20	68	.200	3.14	.9

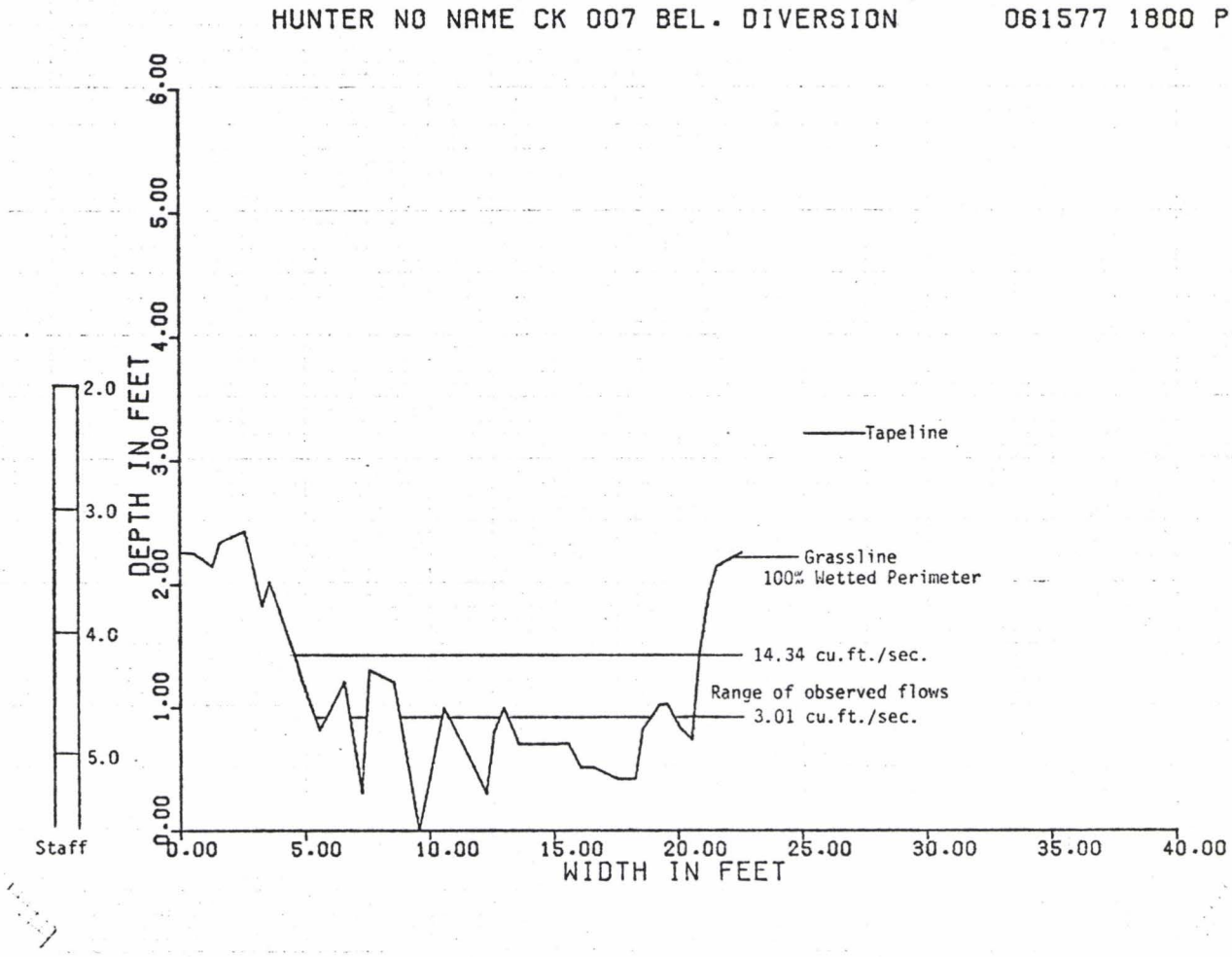


Figure 19. Cutthroat trout collected at station F-1, Hunter Creek, Pitkin County, Colorado, July 27, 1977

Figure 20. Cutthroat trout collected at station F-1, Hunter Creek, Pitkin County, Colorado July 27, 1977

Table 3. Number and weight (lbs.) of fish collected, Hunter Creek Watershed, Pitkin County, Colorado, July 27-30, 1977

Station	Number Cutthroat Trout	Weight Cutthroat Trout	Number Brook Trout	Weight Brook Trout
		Hunter Creek		
H-1, F-1	53	8.93	-	-
H-3, F-2	67	5.13	-	-
H-5, F-3	-	-	135	17.80
H-8, F-4	1	0.30	168	22.70
H-12,F-5	-	-	258	19.13
Total	121	14.36	561	59.63
		Midway Creek		
F-1	-	-	123	13.39
H-10,F-2	-	-	50	6.04
Total	-	-	173	19.43
		No Name Creek		
H-6, F-1	-	-	103	9.25
H-7, F-2	-	-	88	6.25
Total	-	-	191	15.50

The number of brook trout per acre in each of the three streams is about equal (Table 4). The pounds of brook trout per acre in No Name Creek is less than in the other two streams. This is probably a reflection of reduced food supply. However, bottom samples were not collected, therefore this cannot be verified.

Length frequency data for the cutthroat trout population indicates at least two and possibly six age classes of fish in the Hunter Creek population (Figure 21). The youngest group, age 0+ is grouped around 2.1 inches and age I+ fish are grouped around 4.9 inches. Thellocation of the age groups II-IV is not possible to determine without examining scales. However, the largest fish (11.4 inches) is probably V+.

The small number (3) of fish in the 9-11 inch group at station H-3, F-2 compared with the larger number (15) of fish found at Station H-1, F-1 is probably due to fishing pressure in the vicinity of the diversion structure. Station H-1, F-1 is 1.2 miles above the construction site, while H-3, F-2 is about 500 feet below the site, an easy walk from the diversion site.

The brook trout population in Midway Creek exhibits three and possibly four age groups (Figure 22). Age class 0+ is represented by the 1.3 inch fish, age I+ is centered around 4.1 inches and age class II is centered around 6.4 inches. The 10.0 inch fish is probably three or four years old. Without examining scales, this cannot be verified.

The large number (77) of fish in Midway Creek at station F-1 between 6 and 8 inches, compared with the number (27) at station H-10, F-2 in the same inch group is probably due to a cropping effect by fishermen. The number of fishermen using this area is not known, but probably most of the fishing pressure is from construction workers. Station F-1 is located approximately one mile above the construction site, while station H-10 is about one-fourth mile below the site.

The small number (1) of young-of-the-year fish collected in this stream probably reflects the poor over-wintering conditions that existed this past winter. The lack of snow in the area last

Table 4. Number and weight (lbs.) of fish per acre and mile, Hunter Creek Watershed, Pitkin County, Colorado, July 27-30, 1977

	Hunter Creek	Midway Creek	No Name Creek
Number CTT/Acre	273	-	-
Weight CTT/Acre	32.0	-	-
Number CTT/Mile	600	-	-
Weight CTT/Mile	70.3	-	-
Number BRT/Acre	519	384	516
Weight BKT/Acre	55.2	43.2	41.9
Number BKT/Mile	1870	865	955
Weight BKT/Mile	184.0	97.2	77.5

CTT - Cutthroat Trout
BKT - Brook Trout

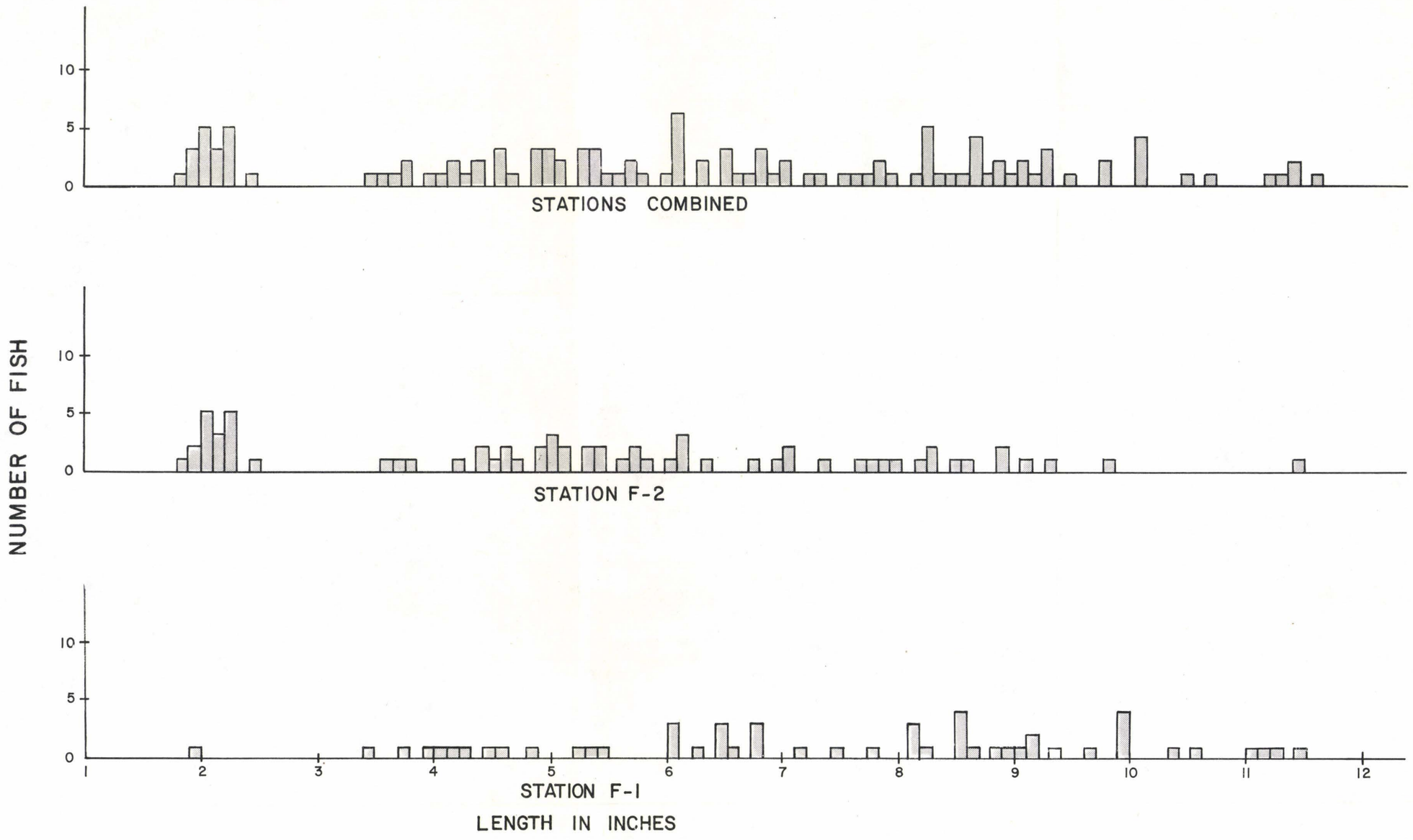


FIGURE 21 LENGTH FREQUENCY OF CUTTHROAT TROUT, HUNTER CREEK, PITKIN COUNTY, COLORADO JULY 27, 1977

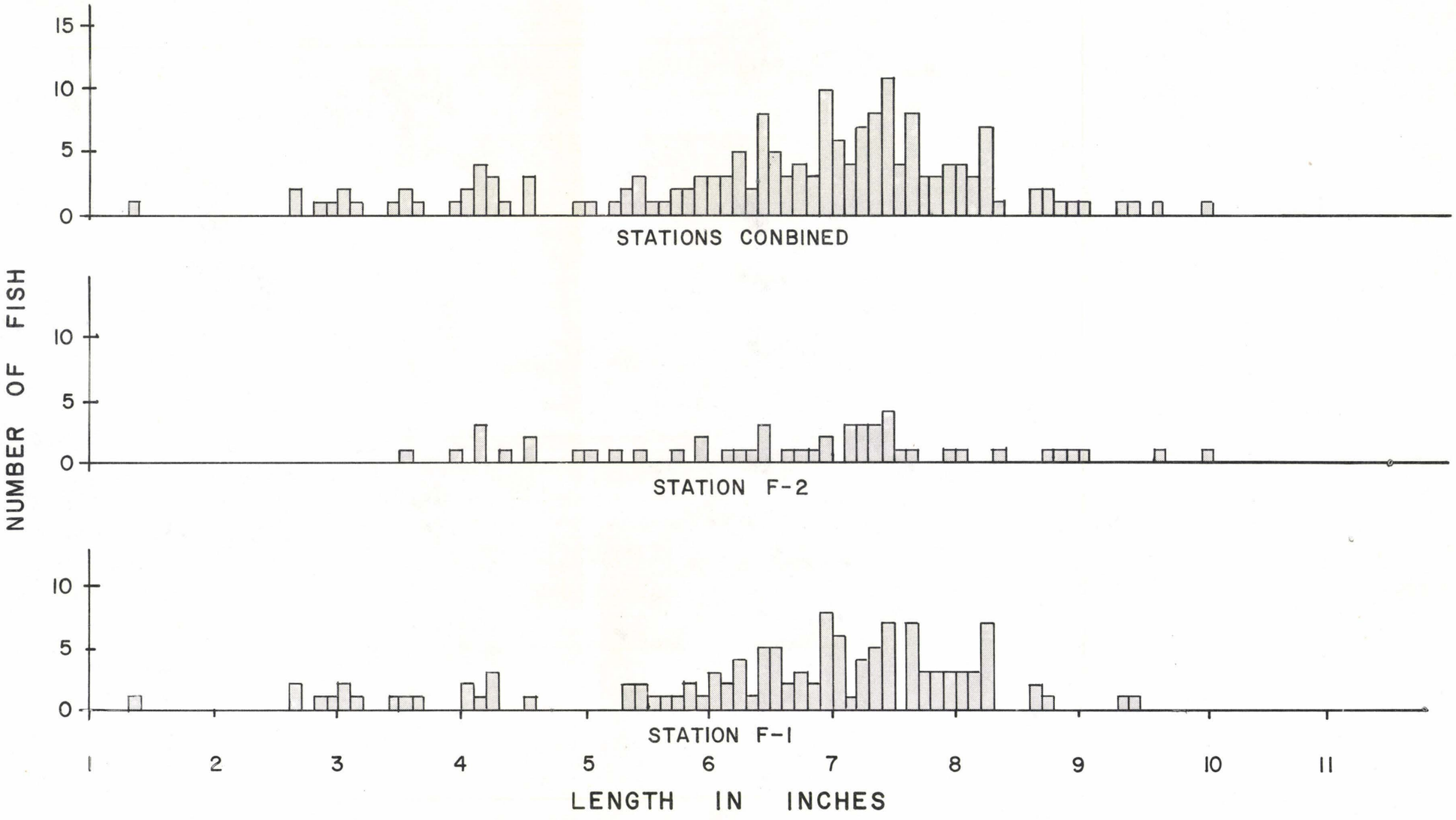


FIGURE 22 LENGTH FREQUENCY OF BROOK TROUT, MIDWAY CREEK, PITKIN COUNTY, COLORAO. JULY 28, 1977

winter probably allowed the streams to freeze to the bottom in most of the spawning areas, thus reducing egg survival.

The No Name Creek brook trout population appears to contain two and possibly five age classes (Figure 23). Age 0+ is at 1.5 inches, age I+ is grouped around 3.5 inches. Ages II-IV could not be determined without examining scales.

Unlike Midway Creek, Station H-6, F-1 and H-7, F-2 on No Name Creek appears to contain similar numbers of fish in the 6-8 inch range. Station H-6, F-1 yielded 62 fish and station H-7, F-2 produced 48 fish in this range.

As with Midway Creek, the lack of a strong 0+ age class in this stream is probably due to poor egg survival over the past winter. Midway and No Name Creeks receive similar snow packs.

The lower Hunter Creek brook trout population contained at least three and possible five age classes (Figure 24). Age 0+ is at 1.9 inches; age I+ is at 4.5 inches and age II+ at 7.3 inches. Age III and IV could not be located without examining scales.

The large number of young-of-the-year (0+) fish in the lower reach of Hunter Creek as compared wi h Midway and No Name Creeks was probably a function of better over-wintering conditions, less stream icing. This was particularly evident at station F-5, the lower most station which yielded the largest number of small ($\leq$3 inches) fish.

Condition factor describes the condition, plumpness or well being of a fish. Table 5 presents the mean condition factor for cutthroat trout in Hunter Creek. These fish appeared in very good condition and the mean condition factor is similar to those reported by Carlander (1969).

The condition factor for brook trout in Hunter and Midway Creeks appears near equal (Table 6). However, the condition factor for brook trout in No Name Creek appears to be lower. This suggests the observation that food supply may be a limiting factor in growth of trout in this stream.

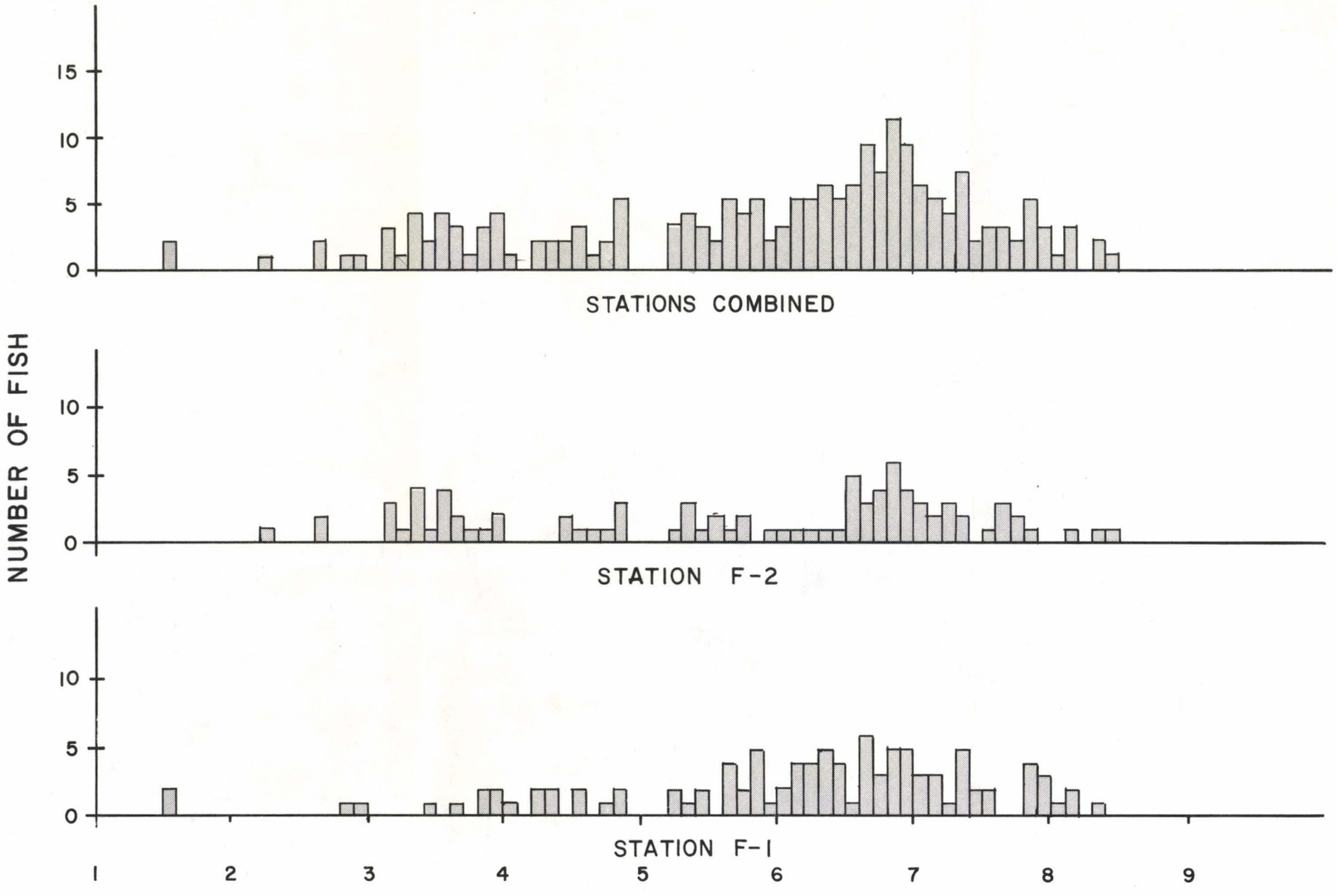


FIGURE 23 LENGTH FREQUENCY OF BROOK TROUT, NO NAME CREEK, PITKIN COUNTY, COLORADO. JULY 29, 1977

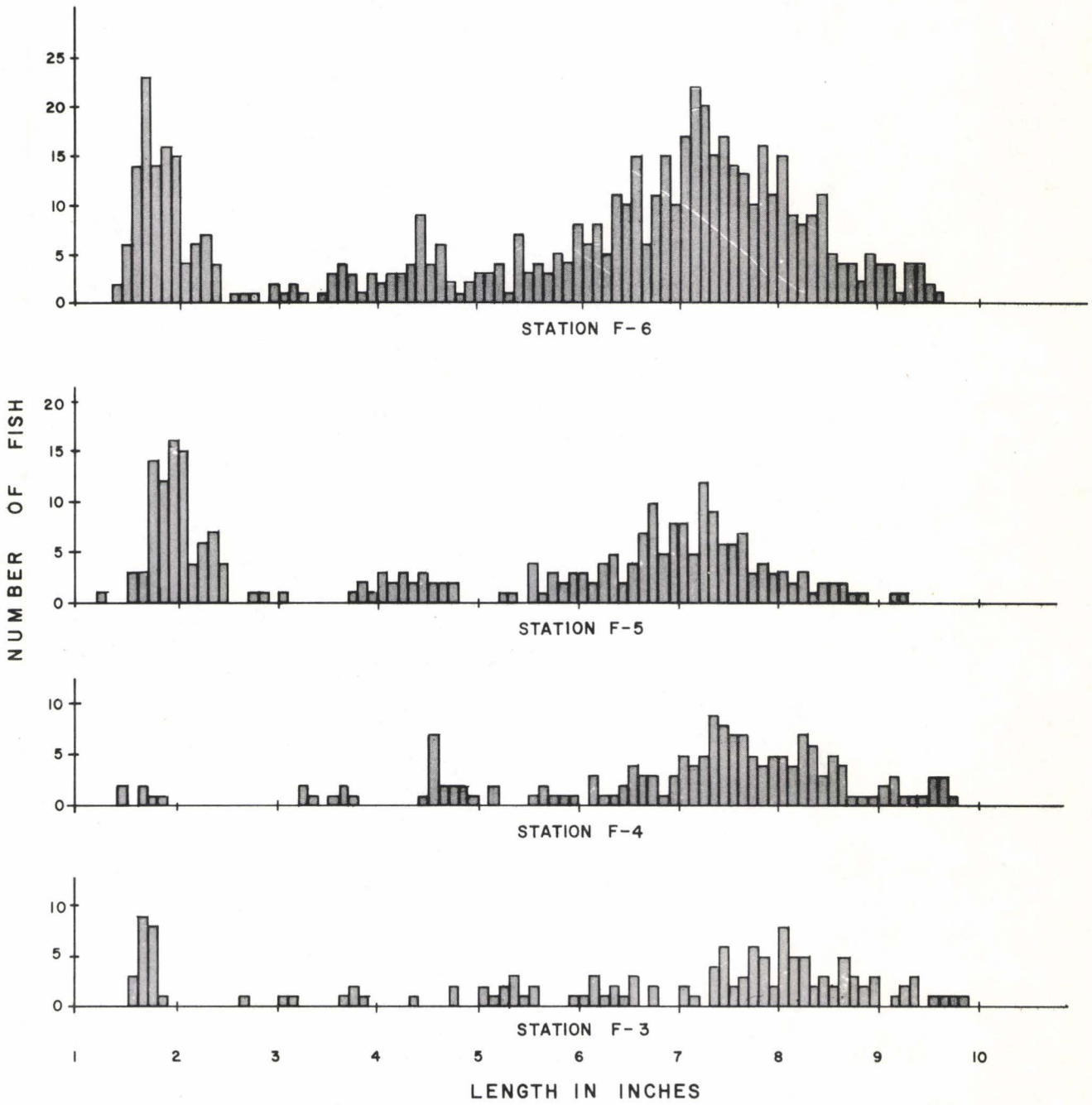


FIGURE 24. LENGTH FREQUENCY OF BROOK TROUT, HUNTER CREEK, PITKIN COUNTY, COLORADO. JULY 28-30, 1977

Table 5. Mean condition factor for cutthroat trout by inch group, Hunter Creek, Pitkin County, Colorado, July 26-30, 1977

Inch Group (Total Length)	Mean Condition Factor	Number Fish
6.0-6.9	32.1	19
7.0-7.9	35.8	8
8.0-8.9	33.2	19
9.0-9.9	32.6	11
10.0-10.9	36.1	2
11.0-11.9	31.6	5
Total	33.1	64

Table 6. Mean condition factor for brook trout by inch group, Hunter, Midway and No Name Creeks, Pitkin County, Colorado, July 26-30, 1977

Inch group (Total length)	Hunter Creek		Midway Creek		No Name Creek	
	Mean condition factor	Number fish	Mean condition factor	Number fish	Mean condition factor	Number fish
6.0-6.9	36.0	84	36.9	46	33.7	66
7.0-7.9	34.8	153	33.6	58	32.8	40
8.0-8.9	33.8	91	31.9	21	32.1	7
9.0-9.9	32.9	28	33.3	4	-	-
10.0-10.9	-	-	29.0	1	-	-
Total	34.7	356	34.4	130	33.3	113

The criteria used to determine the required flows necessary to maintain the streams aquatic resources were based on literature reviews and discussions between Colorado Division of Wildlife, Forest Service and Fish and Wildlife Service fishery biologiszs (Table 7). The values were selected based upon trout species present, size of the fish and spawning requirements. They are representative of the Hunter Creek drainage and cannot necessarily be applied to other locations. Hydrologic criteria for trout production are velocity, average depth and wetted perimeter and are considered to be of equal importance. Because of their close relationship meeting or exceeding two out of the three parameters would maintain the aquatic resources.

Hooper (1973) reported that the cutthroat trout, which spawns between April and early July, have a preferred spawning velocity range of from 1.0 - 3.0 feet per second. A velocity of 1.4 feet per second should be adequate to maintain spawning in Hunter Creek.

The brook trout, unlike the cutthroat trout, is a fall spawner when velocities are normally low. Therefore, a velocity that would maintain the fish and its food supply should be adequate. Wickham (1967) reported that brook trout spent 92 to 96 percent of their time at a given point (home range) in the stream having modal (most frequent occurring) velocities ranging from 0.06 fps to 0.53 fps with an average of 0.33 fps. Maximum velocities ranged from 0.61 to 1.20 fps with an average of 0.86 fps. Considering the home range factor, plus work by Pearson (1970), Surber (1951) and Kennedy (1967), indicating that the maximum number of food organisms were found in stream riffles having velocities of from 1.1 to 2.0 fps, it was concluded that 1.0 fps velocity would be sufficient to maintain the brook trout.

The criteria for average depth on the three streams was determined with regard to the size of the fish present in the streams. Approximately 31 percent of the fish population in Hunter Creek is ≥8 inches. Work by the Colorado Division of Wildlife (1976) indicates that fish of this size range have an average body depth of 2.5 inches.

Another consideration in selecting this average value for the cutthroat trout stream revolves around the maximum age and size this species will attain. Cutthroat trout in Hunter Creek may live to be 7 or 8 years old and be 13 to 14 inches in length. These older fish would have an average body depth of 3.5-4.5 inches. In order to protect these mature trout, an average depth of 0.4 (4.8 inches) foot is needed.

Table 7. Criteria used in determining instream flow needs, Hunter, Midway and No Name Creeks, Pitkin County, Colorado

Average Depths (ft.)	Average Velocity (fps)	Wetted Perimeter (%)
	Hunter Creek	
0.4	1.4	50
	Midway Creek	
0.3	1.0	50
	No Name Creek	
0.3	1.0	50

Midway and No Name Creeks contain brook trout populations that are comprised of approximately 15 and 7.4 percent fish 8 inches or greater respectively. The smaller number of fish 8 inches or greater, plus the fact that brook trout mature at a smaller size and have a shorter life span (usually 3-4 years) than cutthroat trout was the basis for selecting 0.3 foot (3.6 inches) average depth.

Wetted perimeter is related to the total amount of habitat available for food production. At least 50 percent wetted perimeter on all three streams is necessary to maintain the aquatic resources at existing population levels. Also, this will insure sufficient water to maintain the riparian vegetation.

Figures 25-27 display the recommended by-pass flows needed to meet the eszablished criteria at each of the three diversion sites. These flows are: Hunter Creek - 12 cfs, Midway Creek - 5 cfs, and No Name Creek - 4 cfs. By meeting the instream flow needs at the three diversion points, the downstream needs of Hunter Creek will be satisfied to station H-12, F-5.

Water Quality Sampling

The water quality of Hunter, Midway and No Name Creeks remained excellent throughout the field study (Table 8). The quality decreased only slightly at the lower streamflows indicating water quality is not a limiting factor (over the range of observed flows) in determining required instream flows. All measured parameters were above the standards established for cold water fisheries (Table 9). Dissolved oxygen, pH and suspended solids remained relatively constant through the summer while temperature, alkalinity and specific conductivity showed slight seasonal trends, and varied inversely with streamflows.

The increase in stream temperature is attributed to the solar heating as water depths become shallower and exposed rock surface radiated heat to the surrounding water. Temperature extreme ranged from 2 degrees Celsius at Station H-3 to 17 degrees Celsius at station H-12.

The variation in alkalinity and specific conductivity measurements was due to the "diluting effect" of the early season spring runoff. During the spring high flow period, most of the runoff comes directly from high quality snow melt which is very low in carbonates, bicarbonates and dissolved solid concentrations. Consequently, concentrations of receiving streams are diluted, resulting in lower

Figure 25. Hydraulic relationships, station H-3, F-2, Hunter Creek, below diversion, Pitkin County, Colorado

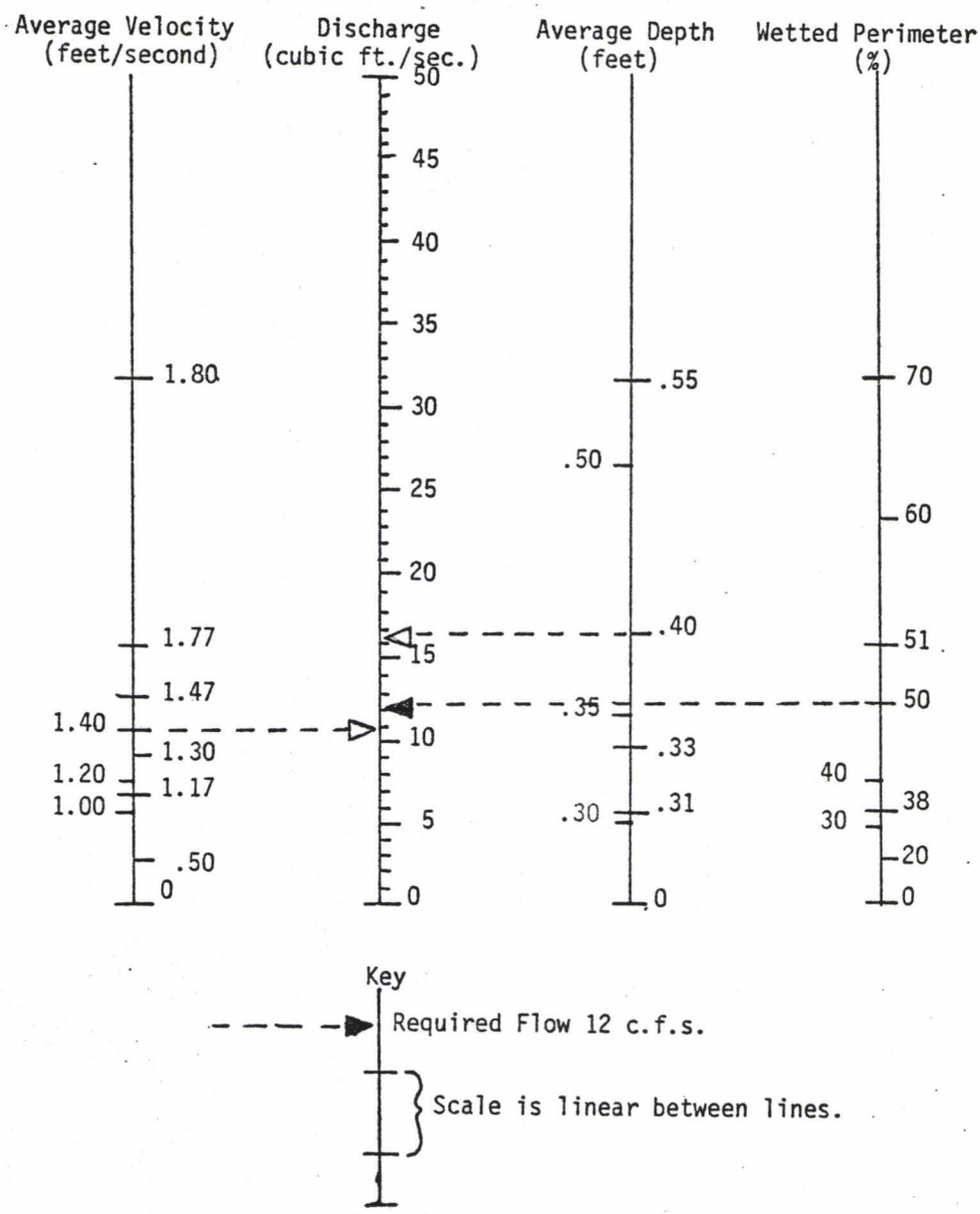


Figure 26. Hydraulic relationships, station H-10, F-2, Midway Creek, below diversion, Pitkin County, Colorado

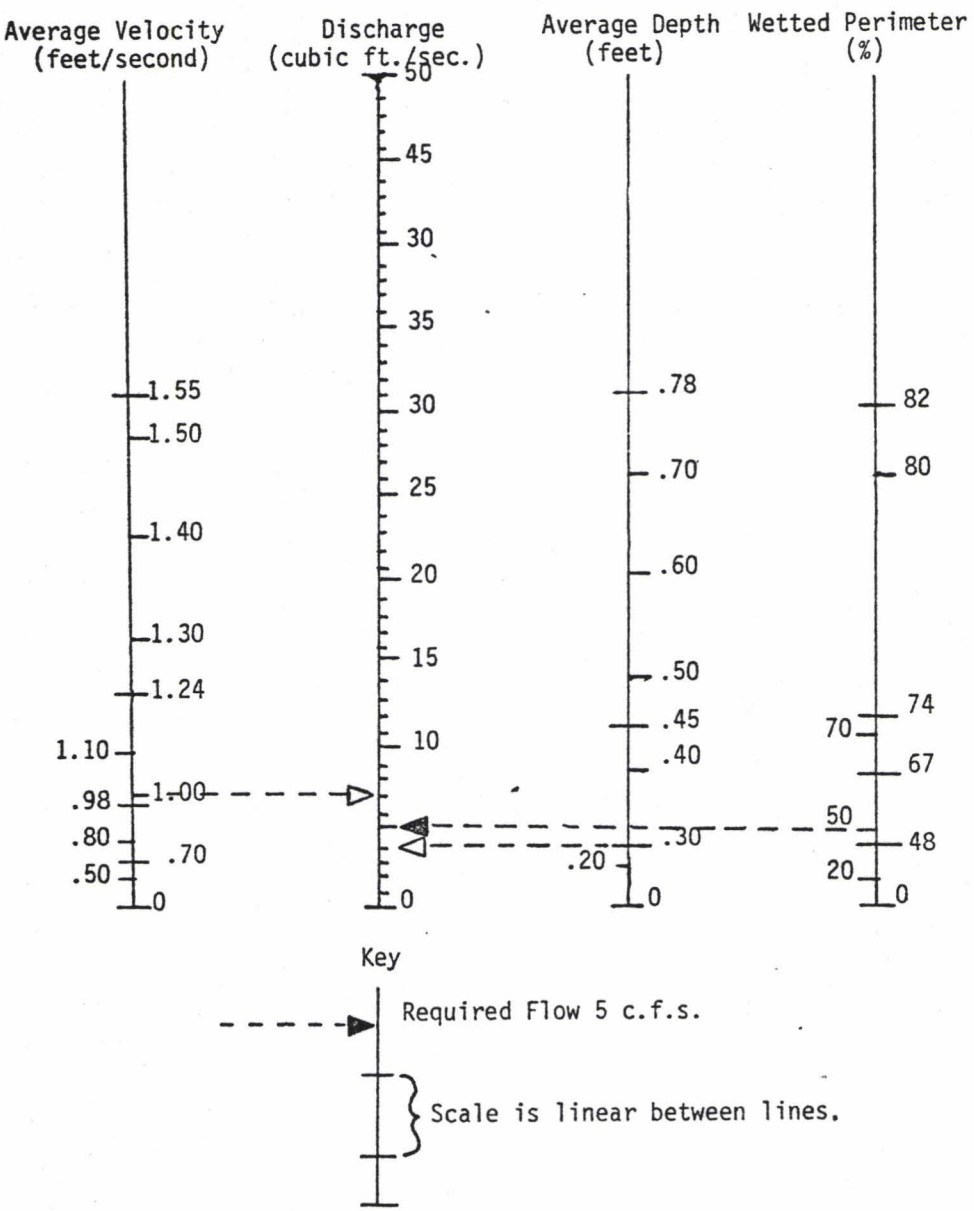


Figure 27. Hydraulic relationships, station H-7, F-2, No Name Creek, below diversion, Pitkin County, Colorado

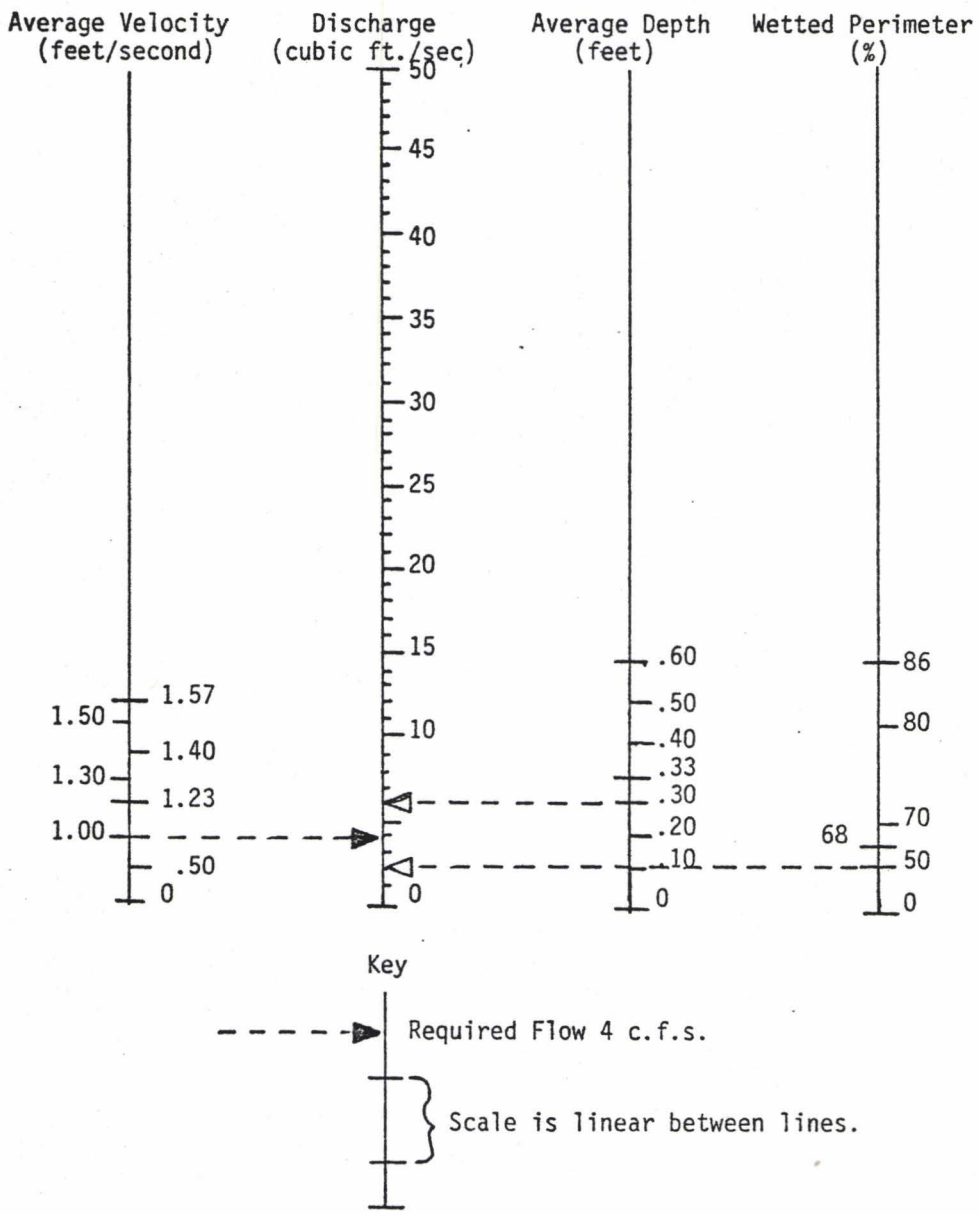


TABLE 8
HUNTER CREEK WATER QUALITY SUMMARY - STATIONS H-1 TO H-12

MEAN
RANGE
NUMBER OF SAMPLES

STATION NO. AND TITLE	TEMPERATURE °C	ELECTRICAL CONDUCTIVITY EC μMhos/cm	DISSOLVED O_2 mg/l	ALKALINITY mg/l	PH - S.U.	SUSPENDED SOLIDS mg/l
H-1 Hunter Creek Above Diversion	7.2 4.0-11.0 7	28.0 19.5-37.5 7	8.4 8-9 7	15.7 13.7-20.6 7	7.5 7.1-8.5 7	1.3 .4-2.4 6
H-2 Hunter Creek Above Diversion	8.2 4.0-13.9 7	28.4 20.0-40.0 7	8.3 8-9 7	13.7 6.9-20.6 7	7.5 7.0-8.7 7	1.1 .2-2.0 6
H-3 Hunter Creek Below Diversion	2.0 - 1	21.0 - 1	10 - 1	13.7 - 1	6.9 - 1	1.0 - 1
H-4 Hunter Creek Below Diversion	8.9 6.0-11.9 7	27.9 23.0-36.3 7	8.6 8-10 7	17.6 13.7-20.6 7	7.6 7.3-8.4 7	3.5 1.8-8.0 6
H-5 Hunter Creek Below Midway Confluence	9.15 6.0-12.2 6	29.3 22.5-35.0 7	8.3 7-9 7	16.7 13.7-20.6 7	7.4 7.2-7.5 7	3.5 .6-12.6 6
H-6 No Name Creek Above Diversion	10.5 8.0-12.2 6	23.7 22.0-27.0 7	7.9 7-8 7	14.7 6.9-20.6 7	7.4 7.0-7.5 7	4.4 .6-17.0 5
H-7 No Name Creek Below Diversion	9.7 8.0-11.1 6	26.8 22.5-42.0 7	7.9 7-9 7	14.7 6.9-20.6 7	7.4 7.1-7.5 7	92.9 .7-480.0 6
H-8 Hunter Creek Below No Name Confluence	7.6 5.0-10.3 6	30.6 24.0-42.0 7	8.3 7-10 7	19.6 13.7-41.2 7	7.4 6.9-7.7 7	2.1 .4-8.67 6
H-9 Midway Creek Above Diversion	9.5 6.0-13.9 6	31.4 25.0-42.0 7	8.1 7-9 7	16.7 13.7-20.9 7	7.4 7.1-7.5 7	2.3 .2-9.0 6
H-10 Midway Creek Below Diversion	10.1 6.0-13.1 6	31.6 25.0-50.0 7	8 8 7	14.7 6.9-20.6 7	7.2 6.8-7.5 7	2.3 .2-9.3 6
H-11 Hunter Creek Above Dam	12.3 8.0-15 7	31.1 24.0-37.5 7	8.4 8-9 7	18.6 6.9-27.5 7	7.5 7.4-7.7 7	2.6 1.0-7.8 6
H-12 Hunter Creek Below Dam	13.9 11.7-16.7 7	42.1 30.0-55.0 7	8.1 8-9 7	25.5 20.6-27.6 7	7.4 7.2-7.8 7	4.3 .8-12.6 6

Table 9. Summary of water quality criteria for coldwater biota (Water Quality Criteria, 1968)

PARAMETER	Cold Water Biota
Temperature	less than 20°C
Suspended Solids	25 mg/l or less
pH	6.5 - 8.5
Dissolved Oxygen	6 mg/l or greater
Specific Conductivity	<1100 micromhos/centimeter

alkalinity and conductivity measurements. Later in the season when streams are less dependent on the snow melt runoff, the concentration of dissolved solids increases and the measurements are higher.

The streams were well oxygenated throughout the summer. Dissolved oxygen concentration varied between 7 and 10 mg/l. The concentrations remained high at lower streamflows due to cold-stream temperatures and good aeration from the turbulent flows of these streams.

Stream pH measurements varied only slightly at different streamflows. The pH values crept upward through the summar reflecting the increased biological and chemical activity of the streams. The average pH value for the 12 sites was 7.4 with ranges from 6.8 to 8.5.

The suspended solids measurements were low with the exception of station H-7. The high values obtained at this site were attributed to stream disturbances from construction activity at the diversion sites. Excluding H-7, measured concentrations ranged from 0.2 to 17 mg/l. This exceptionally low suspended solid content is due to the predominance of erosion resistant rock (granite) in the headwaters and the undisturbed nature of the Hunter Creek drainage.

When flow in a channel is partially diverted, there is a reduction in the stream's capacity to carry sediment. Sediment begins to deposit along the streambed, constricting the channel capacity and adversely impacting the aquatic ecosystem. Sufficient streamflow should be attained periodically to flush the accumulated sediment downstream. The streamflow necessary to move this sediment is dependent on many hydraulic variables including stream slope, roughness, channel geometry and size of the sediment. Analysis of these variables was not within the scope of this study. However, because of the low suspended solid content of the streams and visual analysis of the stable streambed conditions, sediment deposition is not expected to be a major adverse impact. In addition, due to the capacity limitations of the Hunter Creek diversion system, streamflow in excess of the recommended bypass flow will be spilled at the diversion sites (in an average water year). The spillover is approximately twice the average daily flow of the three streams and will probably be sufficient to flush most of the accumulated sediment.

Recreational-Aesthetics

The recreational-aesthetic flow study related to providing streamflows that are characteristic of what naturally occurs during the diversion season. In this case, primarily May through July when stream discharge and velocities are at their peaks, exhibiting turbulent flows. If the diversions completely eliminated this effect and leave only a small tranquil streamflow, then the streams will detract from the surrounding environment.

The required instream flows below the diversion points necessary to maintain the recreational-aesthitic values are as follows:

Hunter Creek Diversion	10 cubic feet/second
Midway Creek Diversion	5 cubic feet/second
No Name Creek Diversion	4 cubic feet/second
Total	19 cubic feet/second

These required flows are similar to the ones necessary to support the fishery. However, this study was conducted independently from the aquatic study by Herb Mittmann, #.S. Forest Service Regional Landscape Architect, Denver, Colorado.

The combined required streamflow of 19 cubic feet/second is 2 cubic feet/second less than the fishery required flows. If the fish requirements are satisfied then the recreational-aesthetic requirements will be satisfied. Alos, the downstream recreational-aesthetic flow requirements will be satisfied if these recommended streamflows are released below the diversions. The study indicates the streamflow needs at the other downstream stations are:

Station H-5, F-3 Hunter Creek Below Midway Confluence	11 cubic ft./sec.
Station H-8, F-4 Hunter Creek Below No Name Confluence	20 cubic ft./sec.
Station H-11, Lower Hunter Creek Above Dam	30-35 cubic ft./sec.
Station H-12, F-5 Lower Hunter Creek Below Dam	30-35 cubic ft./sec.

Recommendations

1. For the protection of the aquatic resource and to satisfy the downstream water needs of the White River National Forest, including recreation, aesthetics, wildlife and riparian ecosystem maintenance, the by-pass flow requirements at the three diversions should be:

   Hunter Creek - 12 cfs or natural flow, whichever flow is less
   Midway Creek - 5 cfs or natural flow, whichever flow is less
   No Name Creek - 4 cfs or natural flow, whichever flow is less

Glossary

Alkalinity - a quantitative expression for the ability of a water to neutralize an acid.

Average depth - measure of a unit depth of stream obtained by dividing cross sectional area by channel width.

Bank flow stage - the stage or depth at which a stream overflows its natural banks.

Breach - a water storage area that has been broken or ruptured.

Cross sectional area - an area of water along a transect line, which is perpendicular to the thalweg line, and is computed by the summation of the products of width and depth figures for rectangular intervals along the transect line.

Dissolved Oxygen - the amount of soluble oxygen in a stream at any given time.

Drainage Area - a quantitative expression describing the area of a drainage basin, where all surface flows are discharged through one outlet or mouth.

Hybridization - production of offspring of genetically differing parents (i.e. - as members of different species).

Hydraulic radius - a geometrical channel description which is obtained by dividing the cross sectional area by the wetted perimeter.

Instream flow - surface flows which occur within the natural channel boundaries.

Manning's streamflow formula - $Q = \frac{1.486}{n}(A)(R^{2/3})(S^{1/2})$ and $V = \frac{1.486}{n}(R^{2/3})(S^{1/2})$ where: Q = discharge, n = roughness coeficient, A = cross section area, V = velocity, R = hydraulic radius and S = slope.

Riffle - a section within a stream which has shallow depths, rapid currents and is influenced by streambed substrate patterns and sizes.

Riparian vegetation - vegetation which occurs along stream channels.

Specific conductivity - a measurement of the electrical conductivity over a potential gradient, which quantifies the degree of ionic concentration within some solution.

Stage - the height of a water surface above an established data point.

Stream gradient - the total fall in elevation between two points on a stream , divided by stream length between the two points.

Stream profile - a plot of the cross sectional area.

Suspended solids - includes organic and inorganic material that is in suspension and may be setteable, but is not a solution.

Thalweg line - a continuous line within the channel, demonstrating the routes of the main current and flow.

Wetted Perimeter - the length of channel that is in contact with stream flow and is in the same plane as the cross sectional area.

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